WATER SAMPLING AND ANALYSIS FOR THE TRACER/TIME-LAPSE RADAR IMAGING TEST AT THE BOISE HYDROGEOPHYSICAL RESEARCH SITE

Elisabeth Hausrath[1,2], Warren Barrash[1], and Edward C. Reboulet[1]

[1] Center for Geophysical Investigation of the Shallow Subsurface (CGISS) and
Department of Geosciences, Boise State University
[2] Department of Geosciences, Pennsylvania State University

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This report describes the logistics, methods, and results for water chemistry sampling and analysis in support of the Tracer/Time-Lapse Radar Imaging Test (TTLT) conducted at the Boise Hydrogeophysical Research Site (BHRS) in 2001. In general, water samples were collected from ~50 locations every four hours during the test and were analyzed in the field for electrical conductivity, temperature, uranine concentration (based on fluorescence), and pH. In this way, breakthrough was monitored in near-realtime, especially at 20 discrete zones in well A1 in the middle of the plume path and several cross-hole tomographic planes.

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ABSTRACT

This report describes the logistics, methods, and results for water chemistry sampling and analysis in support of the Tracer/Time-Lapse Radar Imaging Test (TTLT) conducted at the Boise Hydrogeophysical Research Site (BHRS) in 2001. In general, water samples were collected from ~50 locations every four hours during the test and were analyzed in the field for electrical conductivity, temperature, uranine concentration (based on fluorescence), and pH. In this way, breakthrough was monitored in near-realtime, especially at 20 discrete zones in well A1 in the middle of the plume path and several cross-hole tomographic planes.

Follow-up laboratory analyses at Boise State University included: measurement of fluid electrical conductivity for samples not analyzed in the field; repeated measurements on outliers; evaluation of sample degradation during storage; and determination of the relationship between conductivity and bromide concentration. Overall, outliers (field measurements with deviation from repeated laboratory measurements of >10%) were few indicating that some of the spikes in breakthrough behavior are not due to measurement error. Also, little change in concentration has occurred during storage to date. Post-test review of QC duplicate samples indicates excellent correspondence between duplicates for conductivity, uranine, and pH ($R^2 > .99$, with regression lines forced through zero).

Results for conductivity indicate that breakthrough occurred first in the lower portion of the injection interval in A1, and that breakthrough magnitude decreased upward in the upper half of the injection interval. Although sample analysis is less complete for uranine, it is clear that breakthrough for uranine (relative to conductivity or bromide) was delayed, diminished in relative concentration, and followed a different spatial distribution pattern as indicated by different breakthrough behavior at A1. Follow-up sampling and experiments to test for possible microbiological or biological interaction with uranine suggest that uranine is consumed and perhaps exchanged at cottonwood roots which are known to be present in the aquifer at the BHRS.

INTRODUCTION

This report describes the collection, analysis, and results of water chemistry samples from the Tracer/Time-Lapse Radar Imaging Test (TTLT) conducted at the Boise Hydrogeophysical Research Site (BHRS) in 2001. The basic concept of time-lapse imaging is that variations in the presence of water and/or contaminants may be detectable and quantifiable by recognizing changes in cross-hole measurements collected in the same locations at different times. Examples of such possible locations with environmental concerns are: (a) horizontal planes in the unsaturated zone beneath a pit, tank, or landfill containing or leaking waste; (b) vertical plane(s) in a contaminated aquifer at or up-gradient from a compliance boundary or a drinking water supply well, or immediately up- and down-gradient from a treatment system; and (c) a volume being remediated by air-sparging or being influenced by infiltration. In addition to using time-lapse changes in images to detect and quantify the movement of water and/or contaminants, this same information can also be used to verify or improve models of the three-dimensional distribution of permeability in the shallow subsurface.

TRACER/TIME-LAPSE TEST

A field experiment was conducted to examine the capabilities of time-lapse imaging with cross-hole radar tomography to detect the movement of, and both temporally- and spatially-varying concentrations of, an electrically conductive tracer (analogue for increased fluid electrical conductivity or TDS associated with some types of contaminant plumes) in a shallow, unconfined, heterogeneous, fluvial aquifer (common type of aquifer system that is easily contaminated and difficult to remediate). The test was conducted at the BHRS (Figure 1) (Barrash and Knoll, 1998; Barrash et al., 1999; Clement et al., 1999).

Objectives of the TTLT included: (a) conducting time-lapse radar tomography imaging experiments during a controlled tracer test to demonstrate the ability of this method to detect the presence of, and also temporal and spatial variations in, a tracer plume through cross-sectional and longitudinal planes of imaging; (b) quantifying radar attenuation magnitudes and differences in terms of tracer concentration magnitudes and differences at a central location along the path of the tracer plume (Figure 2); and (c) providing calibration and conditioning data for solute transport modeling.

On August 1, 2001, two tracers (bromide and uranine, or Na-fluoroscein) were injected together to form a nearly-instantaneous "plug" over a 4-m vertical interval near the middle of the unconfined coarse fluvial aquifer (~16-m saturated thickness) at the BHRS. The tracer plug then traveled about 6.9 m along a path approximately parallel to the natural gradient and passed through well A1 which was instrumented with water sampling ports in 20 isolated zones over a 5-m interval centered on the 4-m-thick injection interval. Additionally water samples were collected from six 1-m-thick zones in four wells marginal to the path of the plume (B1, B2, B4, and B5), and a fifth well (B6) which was pumped at ~5 gpm (~20 L/min) to help guide the plume and ensure passage of the plume through well A1 (Figure 2) in ~2 weeks time.

Chronology

For reference, the sequence of events during the TTLT is given in Appendix 1. Greater detail on events listed in Appendix 1 is given in the companion report on the TTLT (Barrash et al., 2002).

SCOPE AND ORDER OF DISCUSSION

This report describes the collection and analysis of water samples from the TTLT in the field and the subsequent analysis of samples in the laboratory, and presents breakthrough results for the two tracers as electrical conductivity (for bromide) and concentration based on fluorescence (for uranine). Also, QC results for these measurements, the relationship for converting conductivity values to bromide concentrations, and field temperature and pH measurements are presented. For convenience of discussion and interpretation, measurements of conductivity and temperature are presented together, and then measurements of uranine and pH are presented together.

Here we note that although uranine was expected to exhibit behavior similar to bromide (i.e., chemically conservative behavior), the observed uranine breakthrough was delayed, was of significantly lower relative magnitude, and displayed a different spatial and temporal pattern at A1 than did bromide. Because of these differences, an additional experiment was designed and conducted to examine if microbiological or biological activity in the aquifer may have affected uranine (see below).

TRACER/TIME-LAPSE TEST LOGISTICS

This section provides an overview of the field aspects of water sampling and analysis during the TTLT. Field operations were maintained with rotating staff on three 8-hr shifts (0600-1400 hr, 1400-2200 hr, 2200-0600 hr) from July 29 to August 18, 2001. The center of these operations was the field laboratory or Chemistry Station (Figures 3-5). Two staff persons were continually present for the 0600-1400 hr and 1400-2200 hr shifts, and one staff person was present during the 2200-0600 hr shift. Responsibilities included: sample collection; sample analysis (including instrument calibration); data recording for near-realtime feedback on results; and cleaning and maintaining glassware and supplies. Each shift managed two sample events. Because of the short staffing for the 2200-0600 hr shift, it was common for the 0300 hr sample event to be collected but only partially analyzed (i.e., A1 samples generally were analyzed but samples from B wells were not analyzed or were only partially analyzed).

FIELD LABORATORY

Water sampling and analysis operations were managed from the field laboratory at the north edge of the central portion of the BHRS (Figures 3-4). The field laboratory was a canopy-covered area with roll-up tarp walls and folding tables that was equipped with instruments to conduct water quality analyses for conductivity, temperature, fluorescence, and pH. About 1/3 of the space in the field laboratory was used for sample analysis (Figures 4-5). Two analytical stations were placed next to each other such that samples from a given event were first analyzed for fluorescence, then for pH (intermittently), and then for temperature and electrical conductivity.

Power was supplied by generator through UPS (uninterruptable power supply) and surge protectors. Deionized water, tap water and miscellaneous supplies were shuttled to the field laboratory on a daily basis as needed. To support analyses, instruments were calibrated and glassware was washed in the field at the field laboratory. Results from analyses were entered into spreadsheets on a portable computer and viewed graphically for near-realtime feedback during the TTLT.

SAMPLING LOCATIONS

The spatial sampling distribution for the TTLT is shown schematically in Figure 2 and to scale by well in Figure 6. Five B wells (B1, B2, B4, B5, and B6) had six 1-m-long sampling zones spanning 6 m centered on the 4-m-thick injection interval (Figure 7), and well A1 had twenty .25-m-long sampling zones spanning 5 m (Figure 8) centered on the 4-m-thick injection interval for a total of

50 sampling locations at these wells (Table 1, Figure 6). The packers between sampling intervals were .075 m long for B wells and A1. Additional description of these packer-and-port systems is given in Barrash et al. (2002).

Each sampling interval had a dedicated tube routed to the surface and then through a cartridge at one of five peristaltic pumps to a fixed outlet above a water-collection trough at a sampling table near the wells (Figures 4 and 9). The labeling convention for sampling zones is a combination of the well name and the sampling zone in sequence from the bottom to the top for a given well. For example, B2-1 is the lowest sampling zone in well B2; and A1-6 is the sixth sampling zone from the bottom in well A1 (Figure 6).

Other locations that were sampled prior to and/or during the TTLT include: (a) the tank in which tracers were mixed prior to injection; (b) the injection line at the outlet from the tracer mixing tank; (c) injection well B3; (d) the discharge hose from well B6; and (e) six 1-m packed-off intervals in A1 at the end of the TTLT after the 20-zone packer-and-port system had been removed and a 6-zone system was installed. The labeling convention for the six 1-m zones in A1 at the end of the test is the reverse of the convention for the rest of the test: zones are labeled by interval first and well name second (again from the bottom up), as for example: 6-A1 is the upper-most 1-m zone in A1 sampled at the end of the test.

SAMPLE COLLECTION AND MANAGEMENT

Water sample collection may be divided into four stages of the TTLT: (a) background sampling before injection; (b) sampling the injection tank prior to sampling injection and the injection line during injection; (c) the main test; and (d) the final portion of the test when well A1 was both pumped and sampled. In addition to well and zone location, each sample is identified by time of collection and by sample event. During each sample event, samples were collected over short time intervals from all or nearly all 50 sampling ports (Figures 4 and 6) and the discharge line. Appendix 2 lists the sample events and identifies each of them with a sequential number and time (clock time and elapsed time relative to start of injection). After injection, there were 102 sample events until the test ended on August 18, 2001. Most sample events occurred at 4-hr intervals during the test (Appendices 1-2).

Water samples were collected in pre-labeled 30-ml amber polyethylene bottles set in labeled trays sized to fit in the water collection troughs below the discharge lines from the peristaltic pumps (Figure 9). Five such trays held 10 bottles each and expedited organization for preparation, sampling, and analysis. Sample lines were rinsed with distilled water prior to insertion into sample bottles.

Sample pumps were run continually at 5 ml/min between sample events to maintain “fresh” formation water in the sampling lines. Pumping rates were increased to 30 ml/min prior to and during sample events to shorten collection times. Although the time of collection for a given sample is identified on the sample label as the clock time of filling, there was a travel time for the water

filling a given bottle and this time varied by pumping rate and by distance through tubing from a given sampling zone (Figure 10). The length of travel time has been estimated for each of the 50 B well and A1 well sampling zones (Table 2).

For each sample event, QC duplicate samples were collected from five or six sample zones after the regular samples were taken. The zones sampled for QC duplicates were selected at the discretion of the staff on a given shift. Time lag between collection of a given regular sample and the corresponding QC duplicate sample ranged from <5 min to ~60 min, with >75 % collected at $\leq$15 min (Figure 11).

Samples were either analyzed in the field or in the laboratory after the test was completed. After analysis ended for a given sample event, sample bottles were collected into a labeled sample event box and placed into a black plastic bag to ensure minimal light exposure. Groups of sample event boxes were delivered to storage at a temperature-controlled building on the Boise State University campus on a daily basis.

Water Management

In addition to routing the discharge from pumping at well B6 at ~20 L/min, two other types of water management associated with sampling and analysis during the TTLT were: (a) collection and removal of water from continuous pumping with peristaltic pumps at 50 sampling zones; and (b) collection and removal of water used for sample analysis and washing of glassware used in sample analysis. Water from continuous pumping with peristaltic pumps was collected at each sampling table from flow through a tube passing from the collection trough to a 5-gal carboy. Collection was necessary to avoid residual contamination with tracers which might otherwise pass rapidly through the highly permeable, very coarse-grained, mineral soil at the BHRS. Ground tarps under each sampling table also helped to minimize this contamination.

Water from the 5-gal carboys was drawn through tubing to a 40-gal collection barrel next to the field laboratory (Figures 3-4 and 12) with a high-capacity peristaltic pump. Water from rinsing and cleaning in the field laboratory was dumped directly into the collection barrel. Periodically, water in the collection barrel was pumped into the main discharge line from well B6 with the high-capacity peristaltic pump.

MEASUREMENT AND ANALYSIS OF CONDUCTIVITY AND TEMPERATURE

Conductivity and temperature are discussed first and together because: (a) conductivity is a measure of the characteristic that attenuates radar signals; and (b) temperature was measured with each conductivity measurement in order to normalize measured conductivity back to a standard temperature.

FIELD MEASUREMENTS

Of the 5521 samples collected during all phases of the TTLT, 4802 were measured in the field for conductivity and temperature (Appendix 3). Samples from well A1 were the priority for measurement in the field, so some B well samples were not analyzed during those shifts when all samples could not be measured. These B well samples were later measured for conductivity and temperature in the laboratory (see below).

Methods and Instrumentation

Conductivity was measured in the field with an Accumet conductivity probe (range 10-2000 uS/cm) and an AR50 Accumet meter. Temperature was measured with a Traceable thermometer (range -50 to 150 °C). According to information provided by the manufacturer, the overall measurement error of the conductivity probe is approximately ±3 % for a given displayed measurement.

The conductivity meter was calibrated and a standard of known conductivity was tested before analysis of samples from each sample event. Here we note, however, that the calibration chart for the conductivity probe only listed values for temperature in the range of 15 to 35 °C, so calibration values in the field for higher temperatures, which were common by afternoon during the TTLT, were based on values extrapolated from the chart.

The conductivity measurement was taken by inserting the probe and the thermometer into the sample bottle and then recording the conductivity and temperature measurements. Both the probe and the thermometer were rinsed with distilled water and blotted dry between measurements to prevent cross contamination.

Since the conductivity instrument does not compensate for temperature, the temperature of each sample was used to correct the conductivity to 25 °C. Since a probe-specific temperature factor was not available, the temperature correction factor from the USGS (1998) was used as shown below:

$$C_{25} = C_m/(1+0.02(T_m-25))$$

where:
C_{25} = conductivity corrected to 25° C
C_m = actual measured conductivity
T_m = sample temperature at time of C_m measurement

Preliminary Conductivity Breakthrough Results

Preliminary breakthrough results from the field are shown for the 20 zones at well A1 (Figure 13A-D); the field results were most complete for A1 and decisions in the field were based on those measurements. Breakthrough results from field measurements of conductivity were preliminary because: QA/QC data had not been evaluated in the field; numerous synchronous spikes in the data

suggested that systematic errors (perhaps calibration errors) may have occurred on some shifts; and some samples were not analyzed in the field due to time limitations.

A low-amplitude breakthrough peak was detected in well A1 (zones A1-6 and above) soon after injection (Figure 13), but conductivity of each zone returned to background or near-background levels soon after injection. The main breakthrough started with gradual rise from about event 20. Two peaks passed through zones 1-7 in A1, and a broad peak (with decreasing magnitude upward) passed through zones 8-14 (Figure 13).

LABORATORY MEASUREMENTS

This section describes laboratory analyses conducted at Boise State University after the TTLT to: (a) determine if concentrations changed progressively with time during storage after the test; (b) evaluate conductivity outliers; (c) complete analysis of conductivity samples not analyzed in the field during the TTLT; (d) complete comparison of QC (duplicate) conductivity samples collected in the field; and (e) determine the relationship for conversion of conductivity measurements to bromide concentrations. Laboratory analyses on a limited number of samples also were run at a commercial laboratory in Boise, Idaho for a quality assurance check. Methods and instrumentation for laboratory analyses were the same as for field analyses except that the ambient temperature was moderate and a standard of known conductivity was tested approximately every hour in the laboratory.

Examination of Possible Sample Degradation During Storage

Since some of the samples were analyzed in the field within several hours of collection and others were analyzed in the laboratory after the TTLT had been completed, we tested 10 samples over a period of approximately 80 days (starting about 3 months after collection) to determine whether their conductivity values changed over time. No clear trend is apparent (Figure 14) although the samples showed a slight increase in conductivity values since the end of the TTLT, probably due to evaporation. Differences in measured conductivity in the samples had a standard deviation of 3.67 uS/cm, or 1.61% of the average of the sample measurements. The degradation test indicates that there was little change of conductivity in stored samples over time, and also provides a measure of the repeatability of the conductivity measurements.

Outliers

Preliminary conductivity breakthrough results at A1 include a number of positive and negative spikes relative to general ambient trends. Also, most of these spikes occur simultaneously at numerous sampling zones although breakthrough behavior varies between zones. These observations suggest that some spikes may be due to an independent source of variation such as systematic measurement error — perhaps due to faulty calibration during a given measurement round in the field.

To examine whether spikes in breakthrough curves (Figure 13) are measurement errors, 111 samples from well A1 were selected visually as potential outliers relative to adjacent data, and were remeasured in the laboratory (Appendix 4). After remeasuring (Figure 15), 50 of the 111 had conductivity values which differed from the field values by more than 3.22%, or two standard deviations of repeat measurements as performed in the laboratory (see above). We used the 3.22% repeatability difference as a basis for judging whether a field measurement was an outlier, and we then replaced those 50 field values with laboratory values (Appendix 4).

QA/QC Review

The total number of regular (i.e., non-QC) samples taken during the main portion of the TTLT (after injection and prior to pumping from A1 after event 97) was 4735. As noted above, the QC (i.e., duplicate) samples were taken shortly after the regular samples (Figure 11). The total number of duplicate samples taken during all portions of the TTLT was 497; 495 of these (or 10.5% of the number of regular samples) were analyzed. Of the 495 analyzed duplicates, 390 were measured in the field. There is excellent correlation (R^2 >.99) for these QC-sample pairs (Figure 16).

Of the 390 QC samples measured in the field, 19 sample-QC pairs had a conductivity difference of >10% (Table 3). On review of the field records for these 19 pairs, several labeling errors were discovered and corrected (Table 3). Correction of these labeling errors leaves 14 sample-duplicate pairs with conductivity discrepancies >10%.

Remaining Conductivity Analyses

Of the 5521 samples collected during the TTLT, 4802 were analyzed for conductivity in the field during the test, and 717 were analyzed for conductivity in the laboratory after the test was completed. The samples analyzed in the laboratory were primarily collected during the 0300 hr sampling times, when only one person was collecting samples, and commonly it was not possible to analyze the B well samples during these shifts.

REVISED CONDUCTIVITY RESULTS

Revised conductivity results include all samples from all wells (i.e., field and laboratory measurements) and adjusted results, as appropriate, based on remeasurement and labeling review.

Background

Before the tracers were injected, 94 conductivity background samples were collected on July 31 and August 1. Those conductivity background samples have an average value of 206 uS/cm and a standard deviation of 5.37 uS/cm, or 2.60% of the average background. This provides an indication of the variation in background and also the minimum variability in the samples. The procedure for correcting samples for background was to subtract a value of 206 uS/cm from the measured, temperature-corrected, conductivity values. It is interesting to note that well B2 showed a

consistently lower conductivity background (average = 203.9 uS/cm) than the other wells (average = 206.4 uS/cm).

Tank and Injection Concentrations

Two samples were collected from the tracer tank prior to injection and eight samples were collected at 4-min intervals during injection. Conductivity results from the tank samples are consistent at 8410 uS/cm; conductivity measurements from the injection line average 8375 uS/cm, with the exception of the sample at 0.5 minutes which was about twice the average value. This high-valued sample was remeasured in the field with a similar result. The 8375 uS/cm average injection-line conductivity value is used as the initial "concentration" (C_o) for the test.

TTLT

Revised conductivity breakthrough results for the TTLT at A1 are presented in Figure 17 which shows all data values that are: (a) not classified as outliers based on initial visual inspection of the breakthrough curves; (b) values initially classified as outliers which were repeatable to within 3.22% upon remeasurement; and (c) lab values replacing those outlier sample values that were not repeatable to within 3.22% upon remeasurement. Most noticeable changes from the preliminary data set (compare Figures 17 and 13) are the removal of several spikes, especially spikes at events 54, 55, 65, 72, 75 and 83, based on QC analysis and remeasurement. However a number of spikes, especially multiple-event spikes, remain (e.g., spikes around events 51, 57, 74 and 85).

Completion of B well conductivity analyses (Figures 18-23) confirms that: (a) the presence of tracer at these wells on the margins of the plume path was limited to the early events associated with injection (with the exception of B1 - see Figure 18); and (b) the up-gradient portion of the injection plume had largely passed through injection well B3 by event 60 (Figure 23), or ~10 days after injection.

Peak breakthrough occurred at about 8 days after injection at ~0.25 C_o in the lower four zones of well A1, with a distinct second peak occurring from day 12 to day 14 (Figure 17A). Peak breakthrough occurred in the next higher three zones in A1 (~0.31 C_o) at ~12 days after injection, after reaching a prior peak at ~0.25 C_o at about 9 days after injection (Figure 17B).

CONDUCTIVITY-BROMIDE RELATIONSHIP

As noted above, the two tracers used during the TTLT were potassium bromide and uranine. Since uranine is only faintly charged, all of the conductivity above the background level is assumed to come from the bromide tracer. Conductivity measurements were performed in the field instead of bromide for rapid feedback and ease of measurement. Here we determine the relationship between bromide and conductivity in the laboratory in order to convert sample conductivity values to bromide concentrations.

Calibration and Measurement

Calibration for measurements leading to the conductivity-bromide relationship takes several steps because: (1) the bromide probe returns a value of potential (mV) rather than a concentration of bromide directly; and (2) comparable conductivity values for bromide standards values must be measured with BHRS background conductivity taken into consideration (i.e., with part of the conductivity magnitude being due to solutes other than bromide). Bromide concentrations in water samples from the BHRS measured prior to the TTLT were below detection level.

We used the AR50 Accumet meter and Accumet bromide (0.4-79,000 ppm range) and conductivity (10-2000 uS/cm range) probes. The measured potential of the bromide probe was correlated with the concentration of bromide solutions by measuring standard solutions, each spiked with 2 ml of Ionic Strength Adjustor per 100 ml of standard, and each using site water rather than deionized water for making standard solutions. A calibration curve was generated from these measurements. To ensure that the system was functioning well, we ran seven concentrations of standard solutions (spanning the range encountered during the TTLT) before and during sample measurement every 1-2 hours, as directed by the manufacturer. We measured the samples in batches of six. Each sample also was remeasured for conductivity. The conductivity meter was calibrated each day, and a conductivity standard run again before measuring samples if more than an hour had gone by since the conductivity meter had been calibrated.

Conductivity-Bromide Relationship

To determine the conductivity-bromide relationship, we selected 22 of the duplicate samples at approximately 75 uS/cm intervals over the range of conductivity measured during the TTLT for bromide analysis (Table 4, Figure 24A). The paired measurements (Figure 24B) yield a linear relationship $y = .9255x + 0$, where y is bromide concentration in mg/L and x is conductivity (measured minus background) in uS/cm. This relationship has $R^2 > .99$ when forced through zero. We used this relationship for determining bromide concentration from conductivity measurements. Here we note that the conductivity-bromide relationship may not be strictly linear above low concentrations (e.g., Bokris and Reddy, 1970), but the error in using this linear approximation is small for the full concentration range encountered during the TTLT (Figure 24B).

QA/QC Checks

Below we present two types of QA/QC checks on the intercalibration of bromide and conductivity.

As one check on the quality of our data, we plotted the molar conductivity (conductivity divided by concentration) corrected for background against the square root of the concentration (Figure 25), which should plot as a straight line (Bockris and Reddy, 1970). A comparison of our data to published experimental data (Lide, 2001) show that although the slopes are different (perhaps due to different conductivities of make-up water), both data sets are linear and the y-intercepts (which indicate the ionic properties at infinite dilution), are similar: 150.43 for our experimental data, and

146.31 for reference experimental data (Lide, 2001). These values also are similar to the value of 151.92 for ionic properties at infinite dilution given by Bard and Faulkner (1980).

As an additional check, we also sent six samples to an extramural analytical laboratory for analysis. The conductivity measurements by this external commercial laboratory and Boise State University are similar with $R^2 > .99$ (Table 5).

Bromide Tracer Recovery

The amount of injected bromide tracer that was recovered from the aquifer during the TTLT may be calculated by: (a) using the conductivity-bromide relationship developed above to convert conductivity to bromide concentration; (b) calculating bromide mass removed during and between sample events based on pumping rate in the discharge line over the time between sample events (usually four hours); and (c) calculating bromide mass removed during and between sample events through peristaltic pumps by apportioning pumping rate over four hours as: three hours at 5 ml/min and one hour at 30 ml/min.

Using this calculation approach, 25.8 kg of bromide were recovered from the discharge through well B6 and 1.5 kg of bromide were recovered from all the sampling zones for a total of 27.3 kg bromide recovered from the aquifer during the TTLT. With 31.5 kg mixed into ~1100 gallons and ~1000 gallons or 28.6 kg injected, the 27.3 kg recovered represents >95% bromide mass recovery.

After the TTLT was completed, six samples were collected from the full saturated thickness of several wells over a period of approximately two months (Table 6) to determine whether the conductivity of the site water had returned to background levels. Considering background to be 206 uS/cm $\pm$10.8 uS/cm, these post-test whole-well samples (average conductivity is 190 uS/cm) are comparable to the average background values for conductivity from all zones prior to the TTLT.

MEASUREMENT AND ANALYSIS OF URANINE AND pH

Uranine and pH were measured in sequence in the field, and uranine fluorescence is pH dependent (Kass, 1998).

URANINE

Of the 5521 samples collected during the TTLT, 4779 were measured for uranine in the field (Appendix 5). From these field measurements it was clear that uranine breakthrough was diminished in concentration and delayed in time relative to conductivity. Subsequently, laboratory analyses were not run for uranine. That is, complete understanding of the anomalous, non-conservative uranine behavior was not as high a research priority as was detailed analysis of conductivity. In this section we describe the methods used to analyze uranine in the field, the results, and QA/QC of the results.

Methods and Instrumentation

Uranine fluorescence was analyzed on 5-7 ml of subsample in clear glass test tubes placed in a Turner Designs AU-10 fluorometer that had been calibrated for uranine concentration. Prior to analyzing samples for a given sample event, liquid uranine standards at 1 ppb, 10 ppb, 50 ppb, and 100 ppb (prepared for the TTLT using site water) and solid standard 10-AU-904 from the manufacturer were run to check calibration. Then samples and QC duplicate samples from a given sample event were measured in the same manner.

Tank and Injection Concentrations

Two samples were collected from the tracer tank prior to injection and eight samples were collected at 4-min intervals during injection. Uranine measurements on the tank samples averaged 87.95 ppb, and uranine measurements on the injection-line samples averaged 88.49 ppb. The injection-line concentration average of 88.49 ppb is used as the initial concentration (C_o) for the test.

Preliminary Uranine Breakthrough Results

Uranine breakthrough behavior is interpreted from the partial analyses completed in the field (Figures 26-32). Two breakthrough events are recognized: (a) a minor "injection peak" which occurred at all B wells except B5, and at most zones in A1; and (b) the main plume peak which appears to have occurred only at some zones in well A1. The injection peak starts within the first few sample events in wells B1, B2, and B4. The injection peak was in the 0.04 to1.8 ppb range ($4.5x10^{-4}$ to $2x10^{-2}$ C/C_o) in wells B1 and B2, and in the 2 to 3.2 ppb range ($2.3x10^{-2}$ to $3.6x10^{-2}$ C/C_o) in B4, but may have arrived later and at barely detectable levels in some zones at well B5. In A1, breakthrough from injection can be recognized in upper zones A8 to A20 during sample events 12 to 25 (Figure 26). This breakthrough behavior shows a progression of decreasing magnitude that occurs progressively later in time downward in well A1 until breakthrough is not detectable in zone 7 or lower zones.

The main plume breakthrough can be recognized in A1 only; this breakthrough occurred in the progression of concentration rate increases: (a) in zones 1 to 14 beginning about sample event 55 to 57 at a low rate; (b) then increasing starting about event 63 in zones 1-12; and (c) increasing again during events in the 80s for zones 1 to 12. Highest measured concentration was observed in zone 9 at 12.15 ppb (.137 C/C_o) during event 93. Where sample analyses extend to the end of the test, the main plume breakthrough ends or drops off abruptly after peaking in sample events in the mid-90s.

QA/QC Review

Of the 4779 samples analyzed for uranine, 387 sample-QC duplicate pairs have been run. Correlation between these samples and duplicates is excellent with $R^2 > .99$ (Figure 33).

pH

Measurements for pH were made on 1239 samples, including QC samples, during the TTLT (Appendix 6) with an Accumet probe. Unfortunately, the instrument used during the TTLT commonly did not calibrate fully, so pH measurements reported here are more uncertain than the ±0.002 pH unit rating of the instrument. Review of the 64 QC duplicate measurements run for pH, however, show that pH measurements are repeatable with an R^2 value of .99 with the regression forced through zero (Figure 34); the R^2 value is .83 if the regression line is not forced through zero.

Measurements of pH at the different zones (elevations) in individual wells show higher pH with depth (except in well B4) and a number of wells have a step increase in pH at ~838 m elevation (e.g., Figure 35). Values typically range from ~6.3 to 7.5. A similar relationship was found when reconnaissance measurements were taken with a multifunctional probe during the summer of 1999 (Johnson and Barrash, unpubl. data, 1999).

CONSIDERATION OF ANOMALOUS URANINE BEHAVIOR

Uranine is known to react sensitively to environmental influences (e.g., Kass, 1998) including: (a) light; (b) pH; (c) temperature; (d) strongly oxidizing chemicals; (e) contamination by organics such as phenols; and (f) biological interaction including microbiological interaction. Some of these influences could have affected concentrations and travel time of uranine, as is discussed below.

Light

Uranine degrades with exposure to light but the experiment was run underground and care was taken to minimize light exposure of samples. The time progressive, zone specific variations in uranine concentration are not consistent with light exposure above ground prior to or after sample collection.

pH

The degree of dissociation of uranine is dependent upon pH such that concentration of the fluorescing anionic form increases with increasing pH to maximal fluorescence at pH >8.5, and with the rate of increase being highest in the pH range of ~5.5 to 7.5 (Figure 11 in Kass, 1998). Initial pH of the injectate for the TTLT was ~6.7; pH in samples from aquifer zones range from ~5.83 to 7.87. Most pH measurements are between ~6.2 and 7.5, and there is a general trend of increasing pH with depth (e.g., Figure 35). Starting with a pH of 6.7 at injection, the maximum increase in fluorescence due to increase in pH would be ~38% of initial fluorescence, or an increase from ~65% of maximal fluorescence at pH 6.7 to ~90% of maximal fluorescence at pH 7.5. This increase in fluorescence would take place in the lower portion of the sampled zones, but the upper portion of A1 had higher uranine concentrations relative to lower intervals in the aquifer there. This pattern is contrary to conductivity distribution and to major pH control on uranine concentrations or fluorescence.

Temperature

Two possible temperature influences are: (1) increased temperature of samples during passage in tubing at the surface to the sampling point; and (2) increased temperature of the measurement subsample in the cuvette of the fluorometer. The maximum difference in the uranine fluorescence between the maximum temperature that we measured (about 40 °C) and the minimum temperature that we measured (about 15 °C) is approximately 10% – the fluorescence at 40 °C is about 90% that of the fluorescence at 15 °C. Kass (1998) notes that after running the Turner Filter Fluorometer 111 for a long time, the cuvette slot had a temperature of 39.7 °C. Raising our coolest samples (15 °C) to this temperature would cause about a 10% decrease in their fluorescence. That is, sample temperature increases due to passage in tubing or time sitting in the fluorometer are insufficient to explain the observed magnitude or patterns of uranine decreases from injection concentration relative to bromide.

Also we note the occurrence of very low-amplitude daily cycles in uranine concentration (Figures 27-28 and 30). The measured sample temperature changes appear to contribute to the daily uranine cycles, but are not sufficient to explain them (i.e., the daily cyclicity remains after temperature-corrected uranine values are plotted).

Strong Oxidizing Chemicals

Uranine may be destroyed by strong oxidizing chemicals (Kass, 1998). Chlorine bleach was used to decompose synthetic drilling mud after drilling (Barrash and Knoll, 1998) and during subsequent well cleaning in 1999. However, considering the modest amount of Na-hypochlorite added, the low oxidation state of aquifer water at the level of the injection zone (Johnson and Barrash, unpubl. data), and the intervening two years until the TTLT was run, it seems unlikely that residual bleach caused the anomalous uranine behavior.

Contamination by Organic Chemicals

The BHRS is a natural area with no development history other than proximity to a storage yard of the Bureau of Reclamation ~150 m southeast of the site. Groundwater recharge is believed to originate mostly from the Boise River which has few industrial uses above the BHRS. No organic contamination is believed to be present in the aquifer at the BHRS, but no analyses have been run to check for contamination with organic chemicals at the BHRS.

Biological Interaction

In some situations uranine may be degraded by microbial activity and may undergo exchange with root hairs (e.g,. Kass ,1998; Vakhmistrov and Zlotnikova, 1990). Lacking other likely causes and finding no *a priori* reason to eliminate biological interaction, a reconnaissance investigation was designed to examine the possibility that biological interaction contributed to the anomalous uranine behavior during the TTLT.

INVESTIGATION OF BIOLOGICAL INTERACTION WITH URANINE

A field and laboratory investigation was conducted in 2002 to determine if microorganisms in the groundwater from the BHRS might cause the decrease in concentration and the delay in break-through for uranine relative to bromide that occurred during the TTLT. In addition, a sample of cottonwood roots was used to test if biological activity associated with them might interact with (i.e., reduce the concentration of) uranine. Water samples were collected from well X3 from the same 4-m elevation interval used during the TTLT. However, well X3 is ~35 m up-gradient from the wells used during the TTLT (Figures 1-2) so we may safely assume that there has been no test-related exposure to uranine at X3 and therefore no preferential selection there for microorganisms which can consume uranine.

Field Sampling

The pump, packers, and tubing used to collect samples from X3 were all sterilized using a dilute bleach solution. After emplacement of the straddle packers to isolate the same 4-m interval as was used for the TTLT, the well was purged for about 25 min at a pumping rate of ~10 gpm until water-quality parameters (dissolved oxygen, oxidation-reduction potential, conductivity, pH, total dissolved gas, and temperature) became stable (Table 7). Water-quality parameters were measured with a multifunctional DataSonde4 operating in a flow cell (Figure 36A) that also had been sterilized using a mixture of alcohol and water. Comparison with data from an in-well profile with the same instrument in well X4 (Table 7), which is representative of a number of wells that were similarly profiled in 1999, suggests that the sampling system likely had a partial air leak.

The volume of water in the well between the packers (10 cm well diameter by 4 m sampling interval length) was approximately 32.4 liters (8.56 gal). With ~30 interval volumes removed and stable water-quality parameters prior to sampling, we believe that water collected for this experiment was representative of water in the aquifer. Twenty-four BHRS aquifer-water samples were collected by filling autoclaved 1-liter Erlenmeyer flasks with 750 ml of water (Figure 36B), and a 1-liter sample was collected for ATP bioassay analysis. The sample for bioassay analysis was kept on ice for transport and then was kept in refrigerated storage at Boise State University until the ATP analysis was performed.

On the same day that the aquifer water-quality samples were collected, a sample of cottonwood tree roots were collected from well X2 where the roots had grown into the well through the well screen at the winter water-table level. That is, the roots were ~.6 m below the water table at the time of sampling (June 3, 2002). Well X2 also is up-gradient from the wells used during the TTLT (Figures 1-2).

ATP Bioassay

An ATP bioassay was performed by Dr. R. Rychert's laboratory at Boise State University on the liter of BHRS aquifer water collected for that purpose. The ATP bioassay found 8.5 nanograms of

ATP/liter. Gram negative pseudomonades have about 0.5 femtograms of ATP/cell. If we assume that most of the microorganisms in groundwater at the BHRS are gram negative, there were approximately 8.5×10^6 to 1.7×10^7 bacteria/liter in the sample. These levels of microorganisms are comparable to levels in Boise River water samples (Dr. R. Rychert, personal communication, 2002). The high levels of bacteria are not surprising given that the aquifer is adjacent to the Boise River (Figure 1) and, based on similar water-chemistry characteristics (Barrash, unpubl. data), BHRS groundwater probably is recharged from the river to a significant degree.

Laboratory Treatment and Analysis for Interaction with Uranine

To test for biological interaction with uranine, water samples were spiked with a range of concentrations of uranine and then were analyzed periodically over an 18-day period to determine if uranine concentrations decreased over time. To ensure that any such change in uranine concentration was due to microbial activity and not to unrelated treatment or handling effects, three types of water samples (each in triplicate) were spiked and analyzed in the same manner. These three types of water samples were: (a) "live" (non-autoclaved) BHRS aquifer water; (b) autoclaved BHRS aquifer water; and (c) autoclaved Boise tap water. Furthermore, prior to filling the flasks in the field or at the tap, each flask was identified with a number and randomly assigned to a treatment to avoid possible flask effects.

Three flasks each of "live" (non-autoclaved) BHRS aquifer water, autoclaved BHRS aquifer water, and autoclaved tap water samples were then spiked with uranine standard to achieve concentrations of approximately 1 ppb, 10 ppb, 50 ppb, and 100 ppb for each triplicate set of each water type. These concentrations were chosen to span the range from injection concentration at the start of the TTLT (~88.5 ppb) to the lowest concentrations of samples taken during the TTLT (<1 ppb). In addition, cottonwood roots that had been collected from well X2 were added to one of the samples of autoclaved BHRS aquifer water with 100 ppb uranine.

The flasks were weighed empty and then again full, so that despite differences in volume due to filling of them in the field, the volume of sample water in each flask (and therefore also the concentration of each solution) could be known precisely. The samples were then incubated in the dark at room temperatures.

The fluorescence of each treatment flask was measured every day for four days, every other day for the next seven days, and every third day for the remaining seven days of the 18-day experiment (i.e., same length of time as the TTLT). The flasks were swirled slightly to ensure that the uranine concentration was completely homogenous, and then a subsample was taken using sterile disposable pipettes for measurement of uranine concentration as fluorescence. Fluorescence was measured using the Turner Designs 10-AU Fluorometer. The fluorometer was calibrated using 100 ppb uranine stock solution. The calibration was then checked before each measuring session using four standards. Corrections for drift and/or slight deviations were performed using the Turner Designs Solid Standard 10-AU-904.

Results

As described above, three types of water samples (live BHRS aquifer water, autoclaved BHRS aquifer water, and autoclaved Boise tap water) were spiked with uranine at 1 ppb, 10 ppb, 50 ppb, and 100 ppb concentrations. No reduction in uranine occurred in any of these samples (Figure 37) over 18 days indicating that free-floating bacteria likely are not the cause for anomalous uranine behavior during the TTLT. However, in the one sample of autoclaved BHRS aquifer water that was treated with 100 ppb uranine and with cottonwood roots that had grown into well X2 over the winter, uranine concentration decreased exponentially with time to ~2% of initial concentration in 18 days (Figure 37D). That is, significant uranine degradation and/or exchange may occur in the presence of the biological and/or microbiological material associated with cottonwood roots. The uranine removal rate in this treatment is consistent with first-order reaction kinetics with a rate constant of 1.8×10^{-2} hr^{-1} (Figure 38). However, the actual reaction processes or kinetics have not yet been defined.

It is interesting to note that uranine concentrations in the live (non-autoclaved) site-water treatments without roots actually increased ~10% for all spike concentrations over the first six days after inoculation, and then remained constant for the remaining 12 days of the experiment (Figure 37). In contrast, the autoclaved site and tap water remained at the same level of fluorescence throughout the course of the experiment. At this point we do not have an explanation for this behavior. Regardless, the lack of decrease in fluorescence in the live site water samples is an indication that microbial degradation of uranine did not take place in the live water samples without roots during the 18-day laboratory experiment.

Discussion

The change in uranine fluorescence in the sample containing root matter clearly indicates that the change is in response to some aspect of the root environment. It has been documented that roots of other species (corn, radish, daffodil) can rapidly uptake uranine at the base of root hairs (Vakhmistrov and Zlotnikova, 1990); from this we speculate that uptake of uranine by cottonwood roots in the aquifer at the BHRS is a possibility. Independent evidence of water uptake by cottonwood roots at the BHRS includes: (a) videolog evidence of sporadic root presence at depth in wells and the presence of root mats that grow at the winter water table in some wells; and (b) a diurnal cyclic pattern in water levels that occurs during the summer (Barrash et al., 2002) when plants are transpiring, but not during the winter (Johnson and Barrash, unpubl. data).

Uranine is generally considered to be a non-sorbing tracer (Kass, 1998). Uranine generally does not sorb onto negatively charged media such as silica and sandstone, but it will sorb onto positively charged media such as alumina and carbonate (Kasnavia et al., 1999; Sabatini, 2000). Since the BHRS consists primarily of silica sand and cobbles, sorption onto the aquifer material is not expected. It is also known that uranine has a strong tendency to sorb onto organic material such as sawdust, humus, and heather (Smart and Laidlaw, 1976). Thus it is also possible that uranine may have sorbed onto cottonwood root or associated organic matter.

Most microorganisms in unconsolidated sedimentary aquifers are attached rather than free floating (Lehman et al., 2001). In addition, the rhizosphere or soil-plant-microorganism system provides a more favorable living environment for microorganisms due to the release or secretion of substrates from the roots (Maier et al., 2000). The progressive decrease in uranine fluorescence in the treatment with root matter may therefore be due to the degradation of uranine by the microbial communities living in the rhizosphere. This explanation is consistent with first-order reaction kinetics or the exponential decay rate of uranine concentration in the autoclaved site-water sample treated with 100 ppb uranine and with cottonwood roots (Figures 37D and 38).

SUMMARY

Water sampling and analysis were conducted as part of the Tracer/Time Lapse Radar Imaging Test (TTLT) in August, 2001 at the Boise Hydrogeophysical Research Site (BHRS) to: (a) determine breakthrough behavior and plume extent during the test; and (b) provide data for quantitative calibration of time-lapse cross-hole radar measurements and solute transport modeling.

A field laboratory was established at the BHRS to provide near-realtime analytical results on tracer concentration changes at 50 isolated zones in: (a) five observation wells; (b) the pumping and injection wells; and (c) the discharge line from the wellfield. The laboratory was operated 24-hr per day for 17 days throughout the test. A total of 5521 samples were collected during all phases of the TTLT from background to pumping from A1. Of these, 4735 samples were collected during the main portion of the test, and 490 QC duplicate samples were collected during the main portion of the test. Measurements in the field laboratory were conducted for uranine concentration (measured as fluorescence), pH (on a subset of samples), fluid electrical conductivity, and temperature.

Most, but not all, samples collected in the field were analyzed in the field. Analyses were nearly complete for samples collected from the 20 zones in well A1; less-complete analyses were run on samples from B wells. These field analytical results guided field activities (e.g., tomography across and along the plume; and decisions on timing, magnitude, and pumping placement toward the end of the test), and identified unexpected tracer distribution during injection and unexpected behavior of uranine overall (significant concentration reduction and transport retardation). Also these results influenced subsequent laboratory analyses (e.g., examination of outliers; decreased emphasis on thorough completion of uranine analyses).

In the laboratory at Boise State University, conductivity outliers were examined, remaining conductivity samples were analyzed, and QC results were checked. In this process, some but not all spikes in breakthrough curves were determined to be errors and have been removed. Excellent agreement between samples and QC duplicates has been demonstrated for conductivity and uranine concentration. Also, the conductivity-bromide relationship was developed with laboratory measurements and was applied to convert conductivity values to bromide concentrations.

A low-amplitude breakthrough peak for both conductivity (bromide) and uranine was recognized at well A1 and most B wells shortly after injection. Then, about six days after injection,

breakthrough from the main bromide plume started to occur first and at relatively greater concentration in the lower zones of A1, and exhibited two distinct peaks in zones 1 to 7. Breakthrough from the main uranine plume occurred significantly later than for conductivity and at a significantly lower relative concentration. Based on sample analyses and review of pumping records, we estimate that ~95% of bromide was recovered from pumping at B6 and from sampling zones with peristaltic pumps.

A follow-up reconnaissance investigation was conducted to test if biological interaction might cause uranine degradation or retardation. Results indicate that biological interaction associated with cottonwood roots degrade uranine, but that free-floating bacteria in the aquifer likely have little effect on uranine concentration.

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Table 1. Locations of packers and packed-off intervals

Well(s)	Midpoint* of packer string	Packed-off intervals
A1	mid-packer of 11th packer from bottom (i.e., packer between zones 10 and 11)	.25 m between packer centers; 20 zones total
B1, B2, B4, B5, B6**	mid-packer of 4th packer from bottom (i.e., packer between zones 3 and 4) Note: *lowest zone is zone 0* for these wells)	1 m between packer centers; 7 zones total
B3	center of 4 m straddled zone (between packers) 1 zone total	4 m continuous zone; holes in pipe

* Packer locations midpoint elevation: ft AMSL = 2752.87, m AMSL = 839.075

** Note: Zones 2, 3, 4, 5 have holes for pumping

Table 2. Time lag from sample zones

Well	Sample Zone	Zone Ele (m AMSL)	Total Distance to Sample Point (m)	Travel Time at 30 ml/min	Travel Time at 5 ml/min
A1	1	836.7	13.6	3.6	21.5
A1	2	836.95	13.35	3.5	21.1
A1	3	837.2	13.1	3.5	20.7
A1	4	837.45	12.85	3.4	20.3
A1	5	837.7	12.6	3.3	20.0
A1	6	837.95	12.35	3.3	19.6
A1	7	838.2	12.1	3.2	19.2
A1	8	838.45	11.85	3.1	18.8
A1	9	838.7	11.6	3.1	18.4
A1	10	838.95	11.35	3.0	18.0
A1	11	839.2	11.1	2.9	17.6
A1	12	839.45	10.85	2.9	17.2
A1	13	839.7	10.6	2.8	16.8
A1	14	839.95	10.35	2.7	16.4
A1	15	840.2	10.1	2.7	16.0
A1	16	840.45	9.85	2.6	15.6
A1	17	840.7	9.6	2.5	15.2
A1	18	840.95	9.35	2.5	14.8
A1	19	841.2	9.1	2.4	14.4
A1	20	841.45	8.85	2.3	14.0
B1	1	836.57	16.05	4.2	25.4
B1	2	837.57	15.05	4.0	23.8
B1	3	838.57	14.05	3.7	22.2
B1	4	839.57	13.05	3.4	20.7
B1	5	840.57	13.88	3.7	22.0
B1	6	841.57	12.88	3.4	20.4
B2	1	836.57	16.03	4.2	25.4
B2	2	837.57	15.03	4.0	23.8
B2	3	838.57	14.03	3.7	22.2
B2	4	839.57	13.03	3.4	20.6
B2	5	840.57	12.03	3.2	19.0
B2	6	841.57	11.03	2.9	17.5
B4	1	836.57	15.96	4.2	25.3
B4	2	837.57	14.96	3.9	23.7
B4	3	838.57	13.96	3.7	22.1
B4	4	839.57	12.96	3.4	20.5
B4	5	840.57	11.96	3.2	18.9
B4	6	841.57	10.96	2.9	17.4
B5	1	836.57	15.88	4.2	25.1
B5	2	837.57	14.88	3.9	23.6
B5	3	838.57	13.88	3.7	22.0
B5	4	839.57	12.88	3.4	20.4
B5	5	840.57	14.32	3.8	22.7
B5	6	841.57	13.32	3.5	21.1
B6	1	836.57	13.75	3.6	21.8
B6	2	837.57	12.75	3.4	20.2
B6	3	838.57	11.75	3.1	18.6
B6	4	839.57	10.75	2.8	17.0
B6	5	840.57	9.75	2.6	15.4
B6	6	841.57	8.75	2.3	13.8

Table 3. Conductivity QA/QC duplicates with differences greater than 10%

Event	Sample Zone	Conductivity Sample (uS/cm)	Before Retest QC (uS/cm)	Percent Difference	Labeling Error
2	B4-5	772.3	491.8	-36	
3	A1-16	220.4	194.6	-12	
4	A1-19	215.1	286.8	33	
4	A1-8	218.1	309.8	42	
4	B5-2	278.8	313.8	13	
17	B1-1 or 7	205.3	251.9	23	Really A1-7, now 1.6% diff.
19	B6-5	228.3	187.2	-18	
27	A1-10	272	232.5	-15	
33	A1-13	240.5	293.2	22	
36	A1-13	231.8	422.9	82	QC really A1-3, now 8.2% diff.
36	A1-8	407.5	230.7	-44	QC really A1-18, now 5% diff.
42	A1-12	318.2	262.4	-18	
53	A1-7	747.9	853	14	
66	A1-13	273.8	233.8	-15	273.8 should be 223.8 (see “7")
76	B6-2	219.6	262.8	20	
79	B2-5	177.4	196.5	11	Really B5-2, now 2.1% diff.
87	A1-5	1036	175.3	-83	
87	B2-4	178.9	258.2	44	
92	A1-15	227.4	386.6	70	

Table 4. Conductivity samples used for developing the conductivity-bromide relationship

Event	Sample	Corrected Conductivity (uS/m)
18	B2-5QC	185.2
25	A1-9 QC	264.2
34	A1-6QC	361.7
43	A1-10QC	409.6
61	A1-11QC	470.0
70	B6-3 QC	501.1
44	A1-6QC	548.9
64	A1-11QC	641.0
46	A1-5QC	702.0
76	A1-9QC	777.8
89	A1-7QC	783.6
82	A1-2QC	889.1
68	A1-1 QC	1028
75	A1-1QC	1051
55	A1-7QC	1061
67	A1-4QC	1274
74	A1-3QC	1426
84	A1-7QC	1660
64	A1-6 QC	1976
83	A1-6 QC	2021
86	A1-6 QC	2073
78	A1-5QC	2329
77	A1-5QC	2436

Table 5. Comparison of conductivity results from external laboratory with Boise State University analyses

Event	Sample	Conductivity (uS/cm) Boise State University	Conductivity (uS/cm) External Laboratory
17	A1-7 QC	249	237
42	A1-8 QC	575.7	518
81	A1-8 QC	1068	1110
50	A1-2 QC	1579	1580
52	A1-3 QC	2033	2140
73	A1-5 QC	2528	2670

Table 6. Post-test electrical conductivity water sample results

Date	Well(s)*	Corrected Conductivity (uS/cm)
9/11/01	B2 and B5**	194
9/11/01	B3 and B6**	199
10/15/01	B3	170
10/19/01	C6	197
10/20/01	C6	193
11/5/01	A1	185

* Samples from full saturated thickness of about 15 m

** Samples from combined discharge of two wells pumping simultaneously

Table 7. Stable water-quality parameter values during collection of water samples from well X3 for microbiological analysis, and comparison data set from in-well profile in X4.

	Start of Sampling Flow-Cell, X3 Water June 3, 2002	End of Sampling Flow-Cell, X3 Water June 3, 2002	In-Well Profile X4 June 22, 1999*
Water Temperature (degree C)	13.6	13.7	13.1
Dissolved Oxygen (% Saturation)	22.0	20.5	1.5
Oxidation-Reduction Potential (mV)	256	279	175
Electrical Conductivity (uS/cm)	200	196.8	185
pH	7.92	7.73	6.7
Total Dissolved Gases (mm Hg)	729	789	735

* Data from T. Johnson and W. Barrash

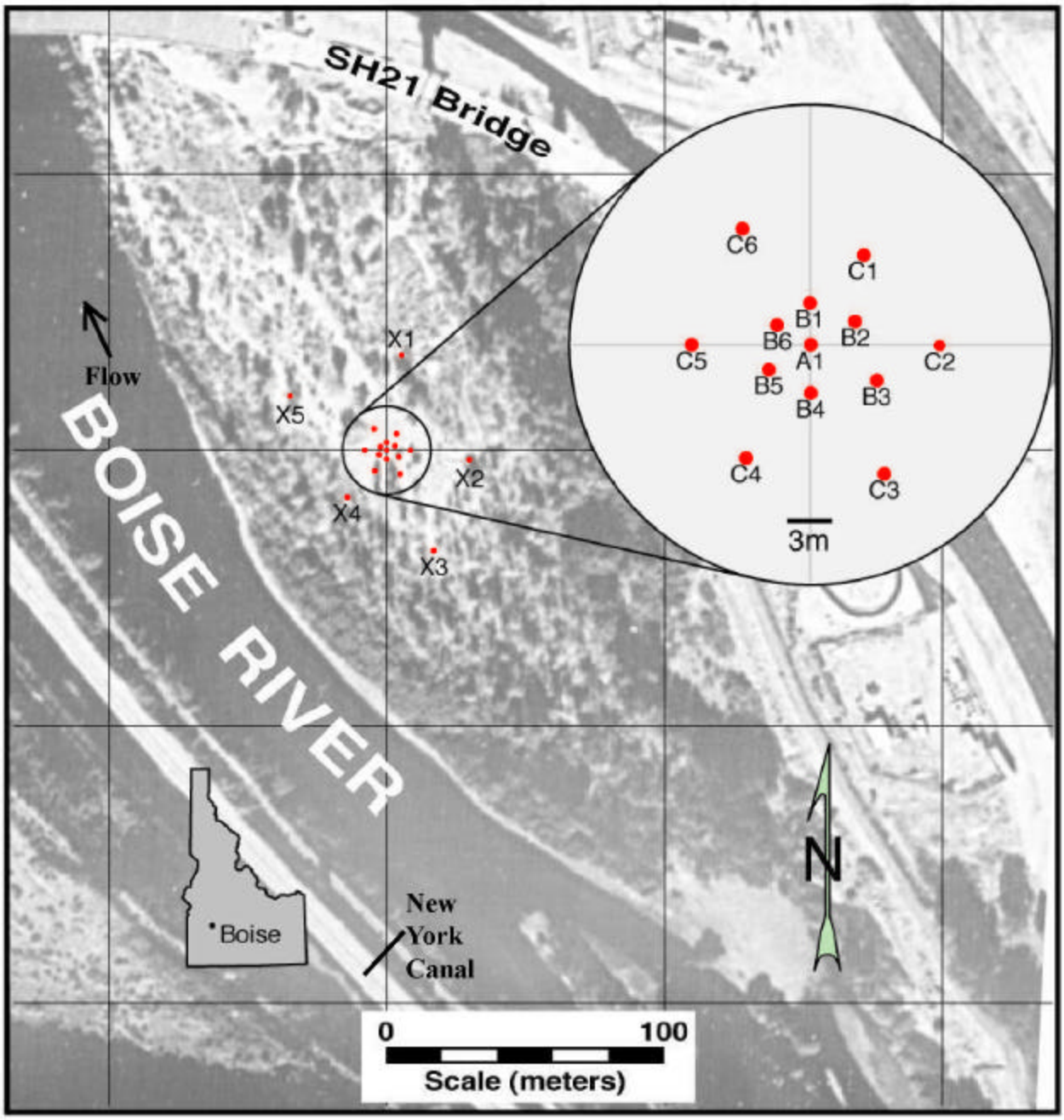


Figure 1. Air photo showing location of the Boise Hydrogeophysical Research Site and wells at the site.

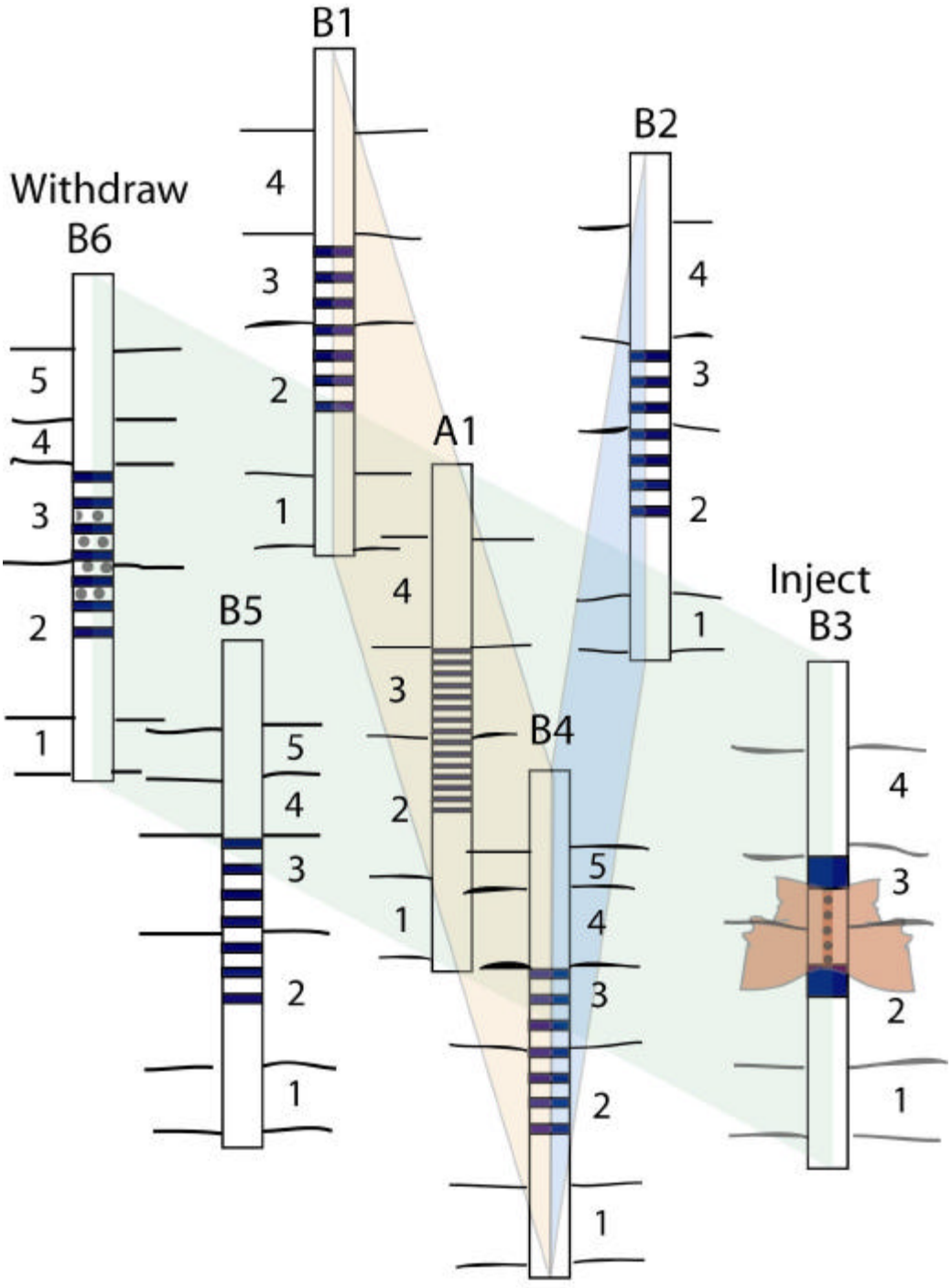


Figure 2. Schematic diagram of initial concept for tracer test with time-lapse radar tomographic imaging at the BHRS.

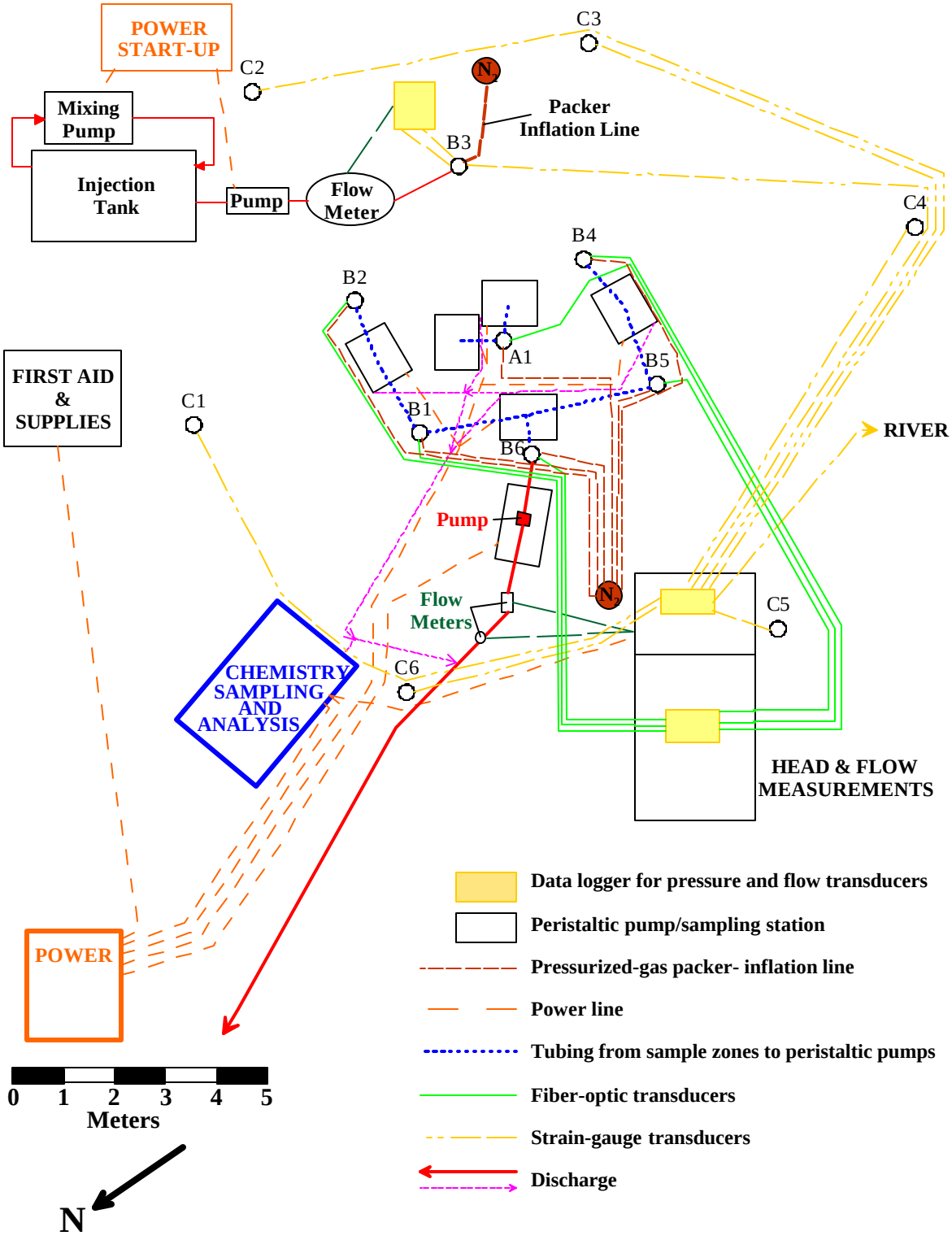


Figure 3. Schematic diagram of arrangement of logistical features at the BHRS for the TTLT.

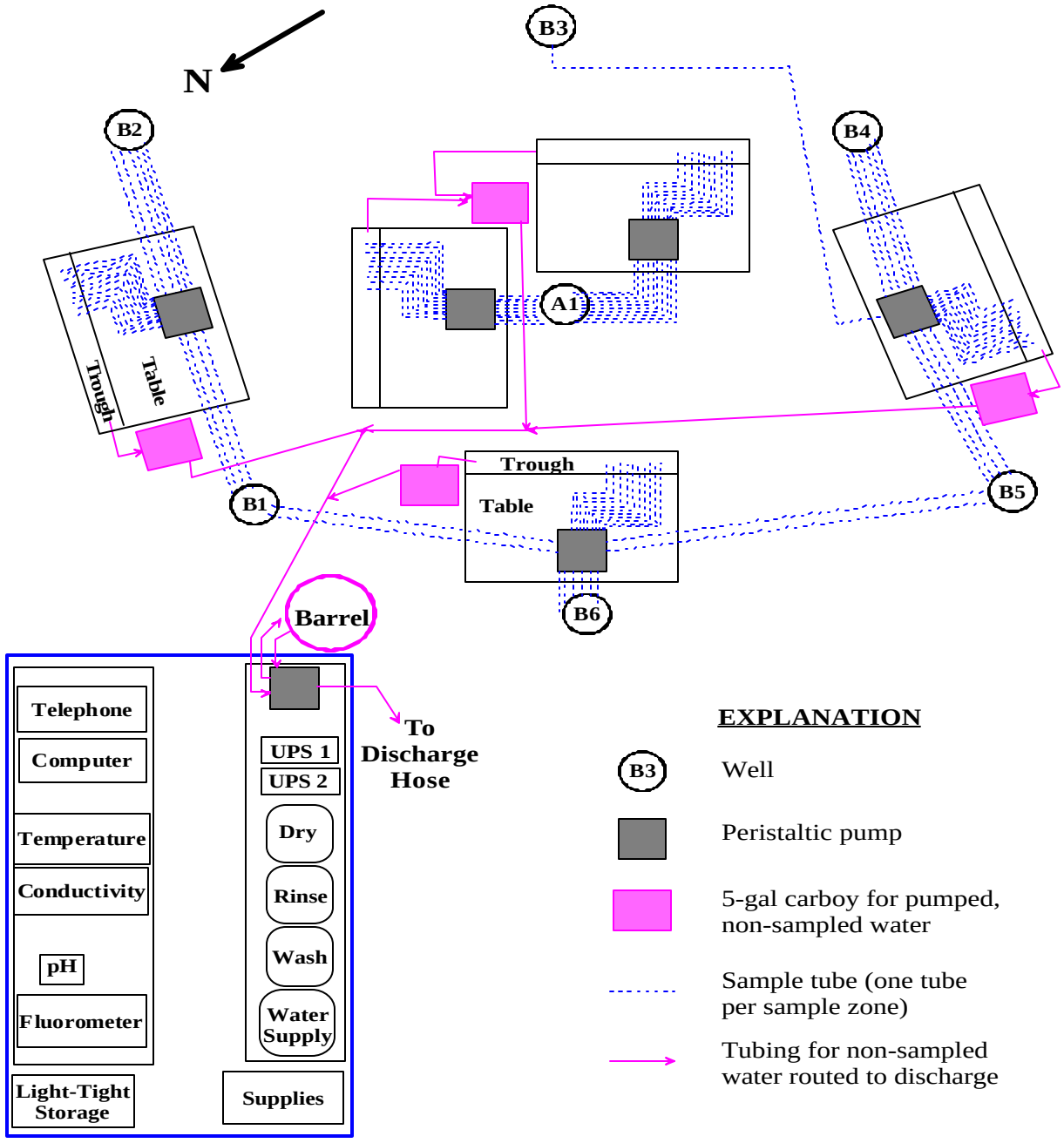


Figure 4. Schematic diagram of logistical arrangements for water chemistry sampling and analysis during the TTLT at the BHRS.

Figure 5. Photograph of the field chemistry laboratory.

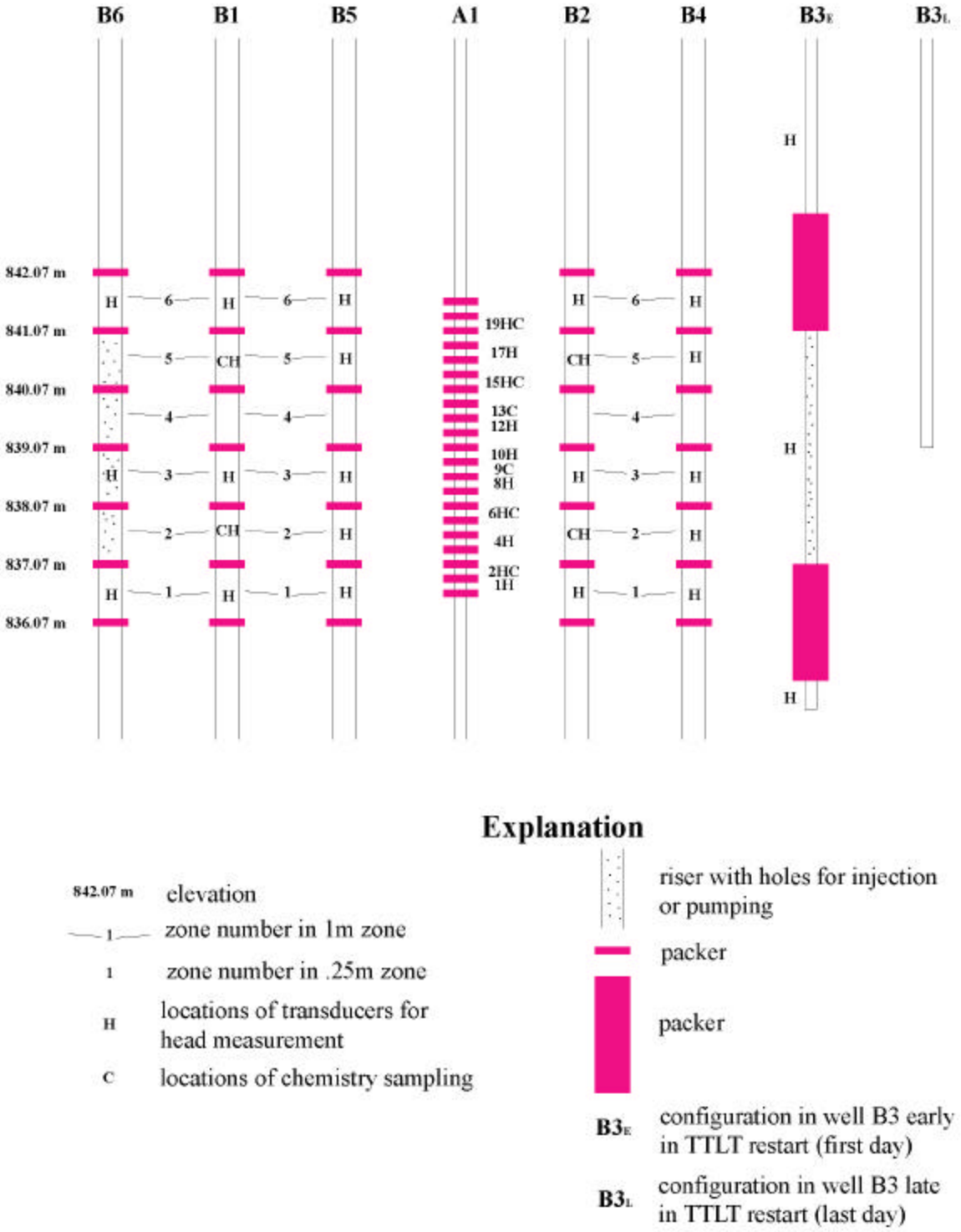


Figure 6. Schematic diagram of packer locations for the TTLT, and of head measurement and sampling zones for TTLT Restart in 2002.

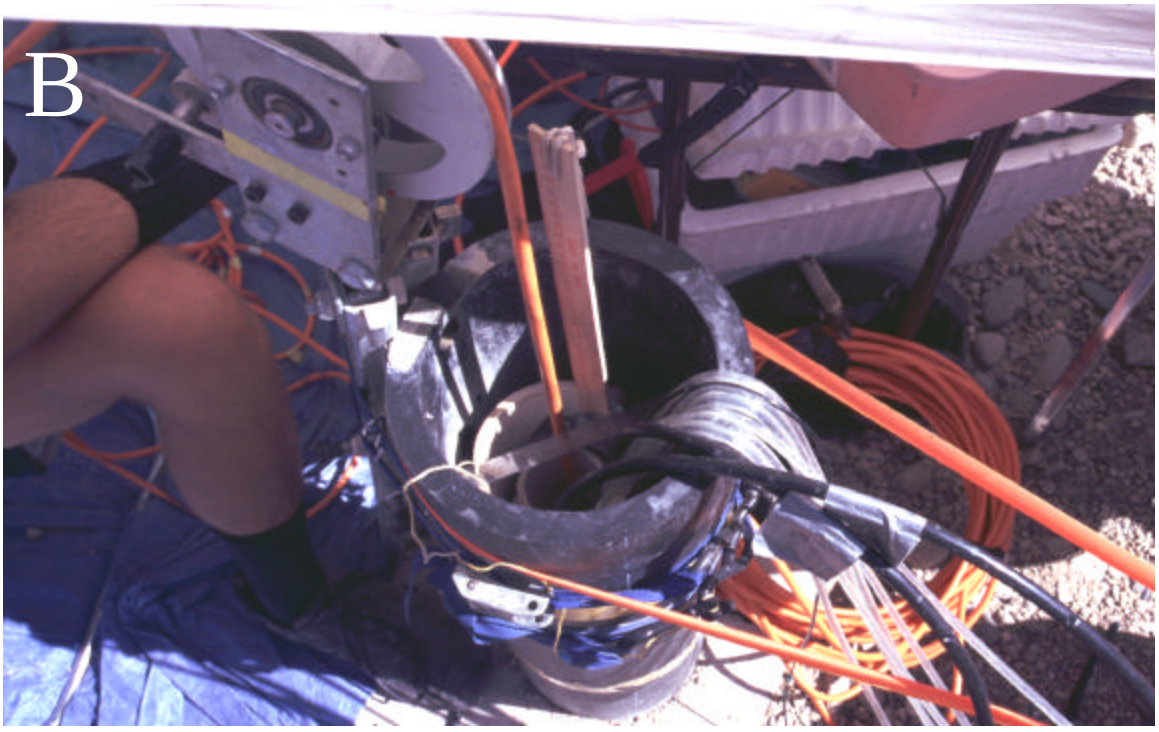


Figure 7.
A. Photograph of custom log-through packer and port system with 1-m separations.
B. Photograph of geophysical logging (i.e., radar tomography) inside custom log-through packer and port system in well B4.

Figure 8. Photographs of custom packer and port system with twenty .25-m-long isolated zones.

A. System being assembled and installed in well A1.

B. Twenty water sampling lines, four head-change lines, and one packer inflation line coming from well A1 during tracer/time-lapse imaging experiment at the BHRS.

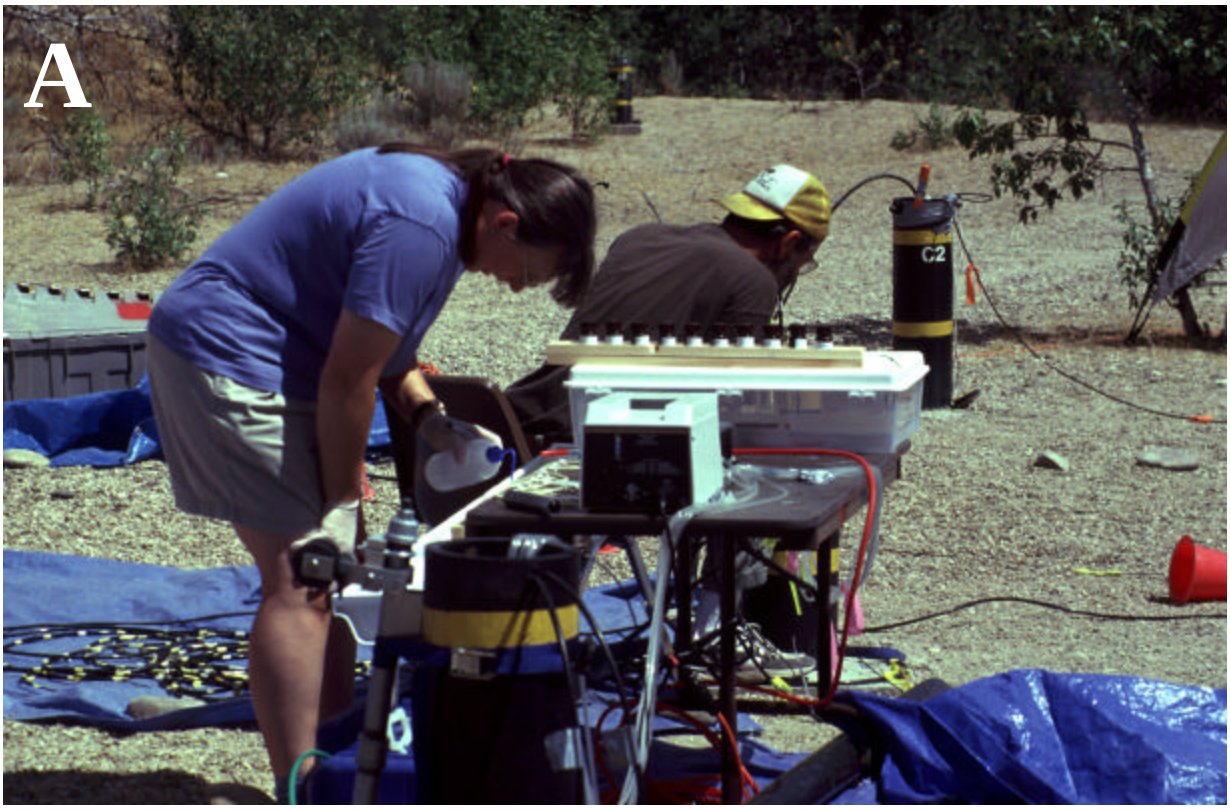


Figure 9. Photographs of sampling.

A. Rinsing dedicated sampling lines with deionized water prior to sample collection. Note 10 pre-labeled amber vials in sample tray.

B. From a peristaltic pump drawing from 10 isolated zones in wells B1, B5, and B6.

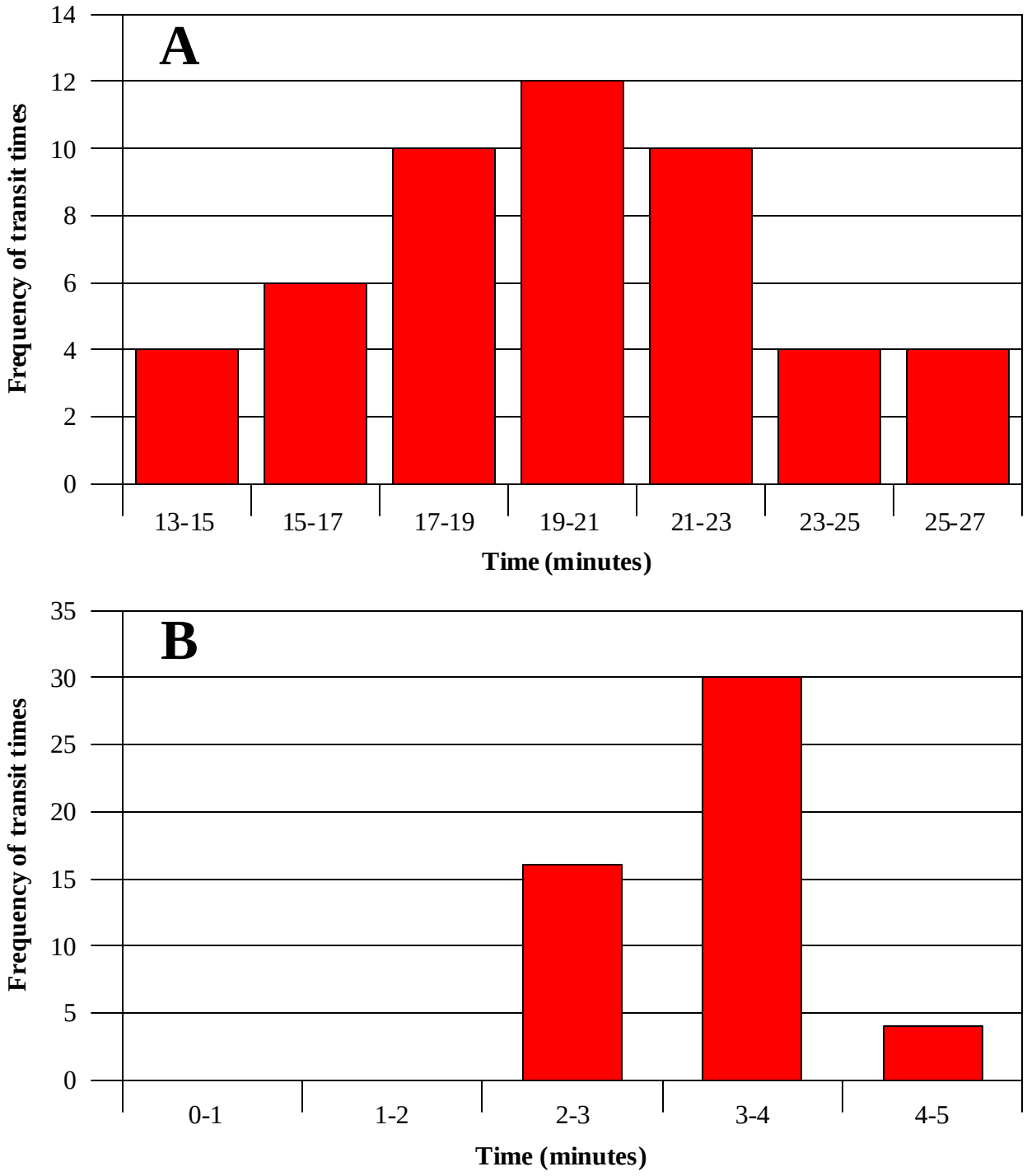


Figure 10. Transit time from sampling zone in the aquifer to sampling point at the surface.
A. At 5 ml/min pumping with peristaltic pump.
B. At 30 ml/min pumping with peristaltic pump.

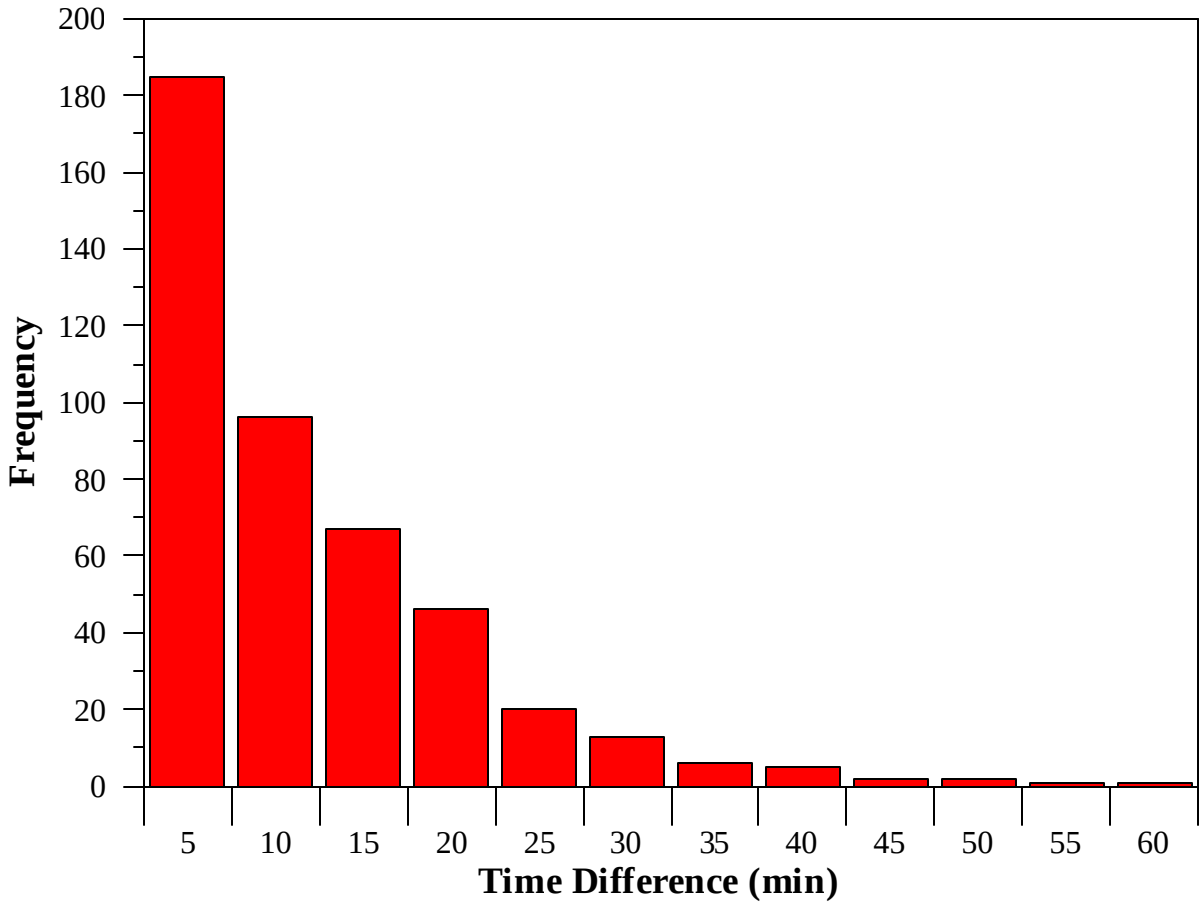


Figure 11. Time lag to collection of QC samples; n=444.

Figure 12. Photograph of discharge systems.

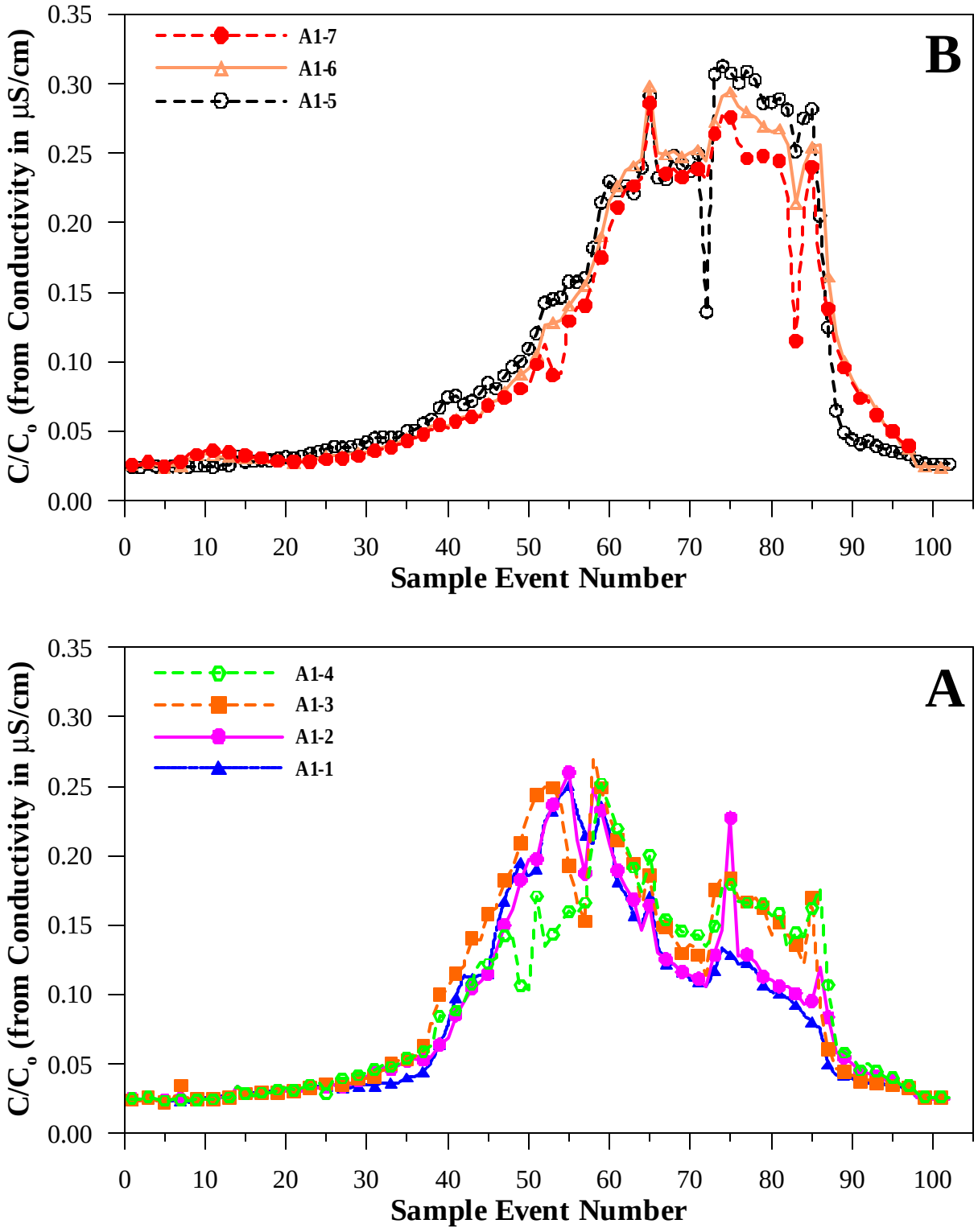


Figure 13. Breakthrough curves (unadjusted for outliers) for conductivity in well A1. A. Zones 1-4. B. Zones 5-7. C. Zones 8-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

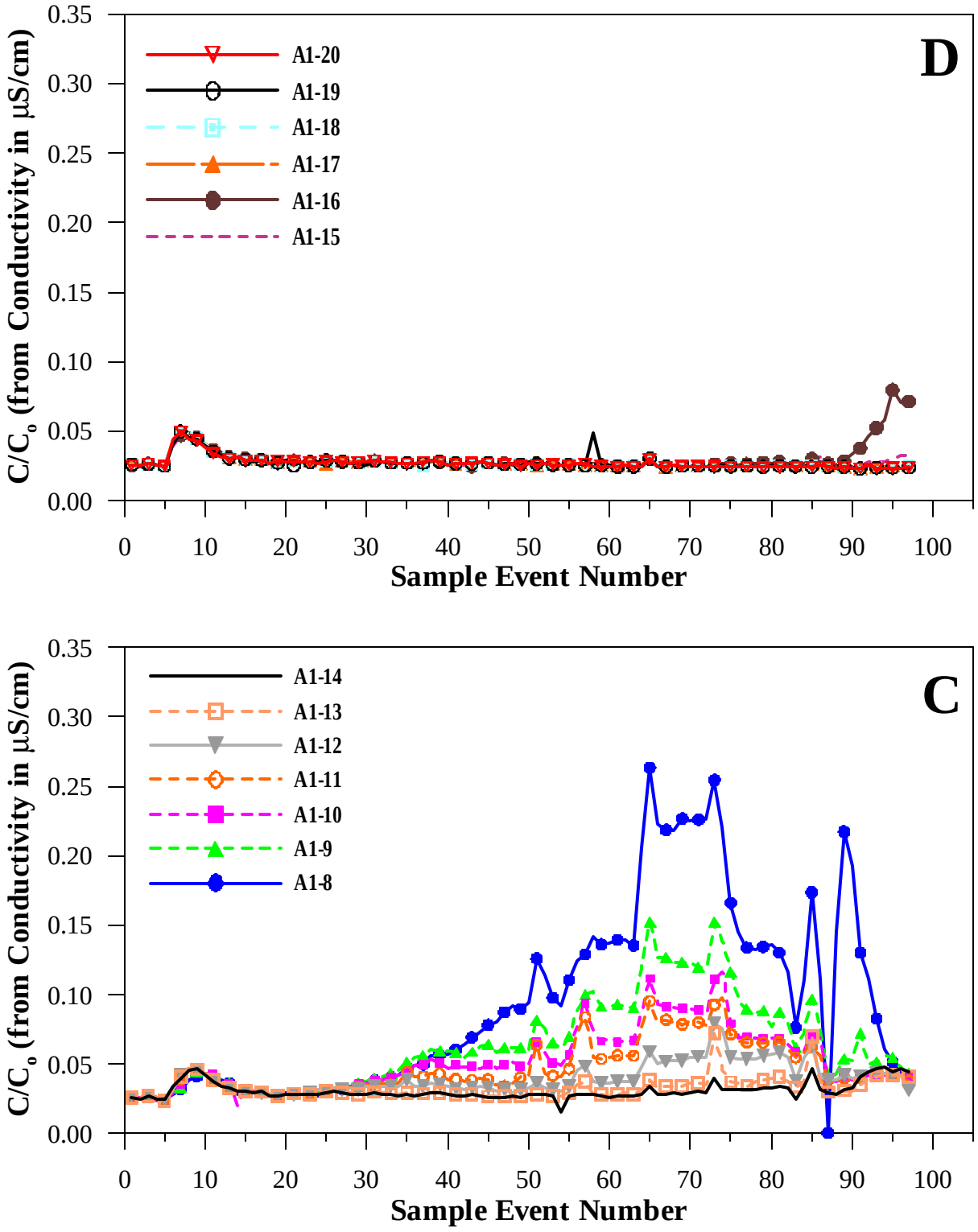


Figure 13. Breakthrough curves (unadjusted for outliers) for conductivity in well A1. B. Zones 1-4. B. Zones 5-7. C. Zones 8-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

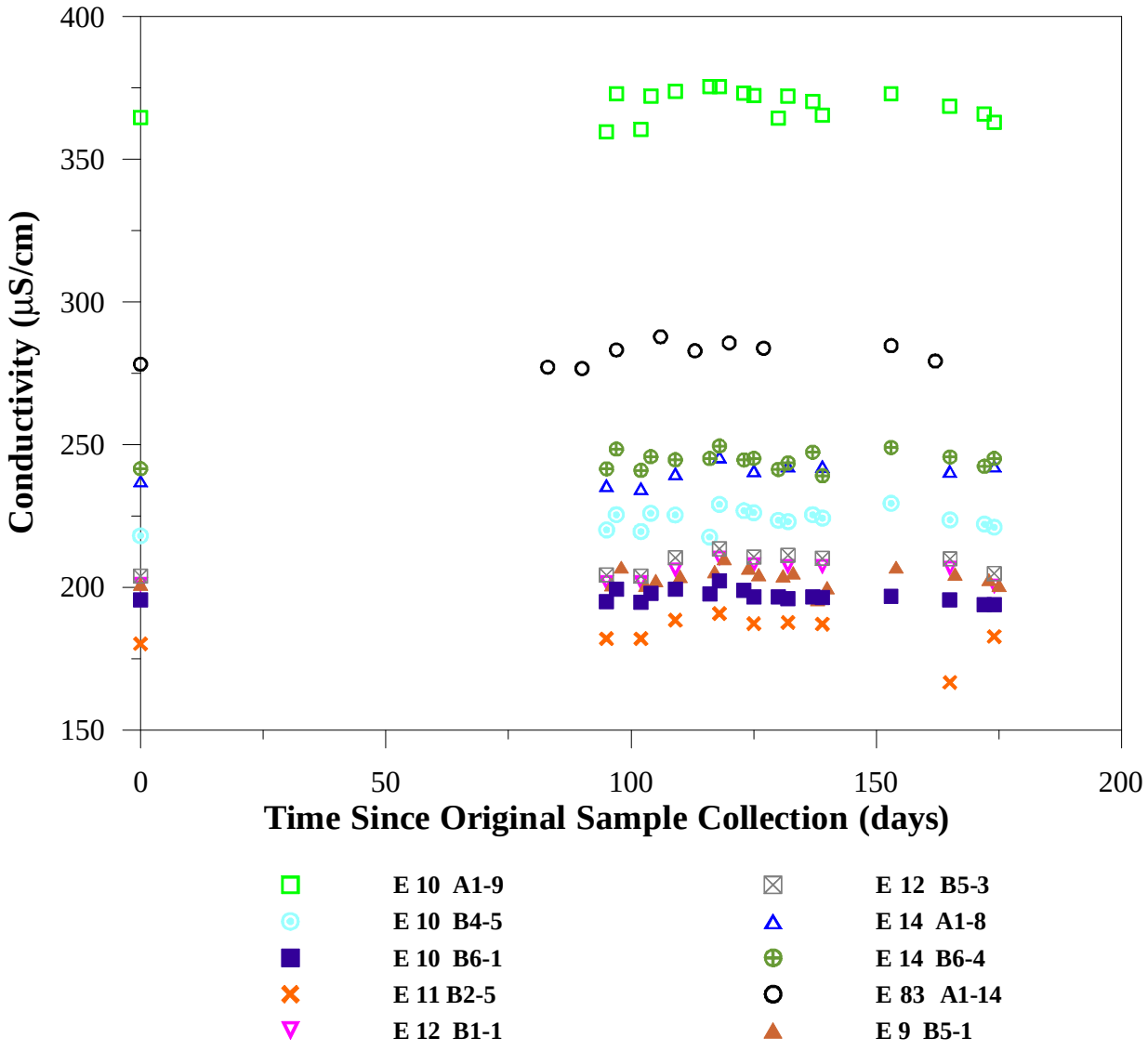


Figure 14. Examination of sample degradation with time.

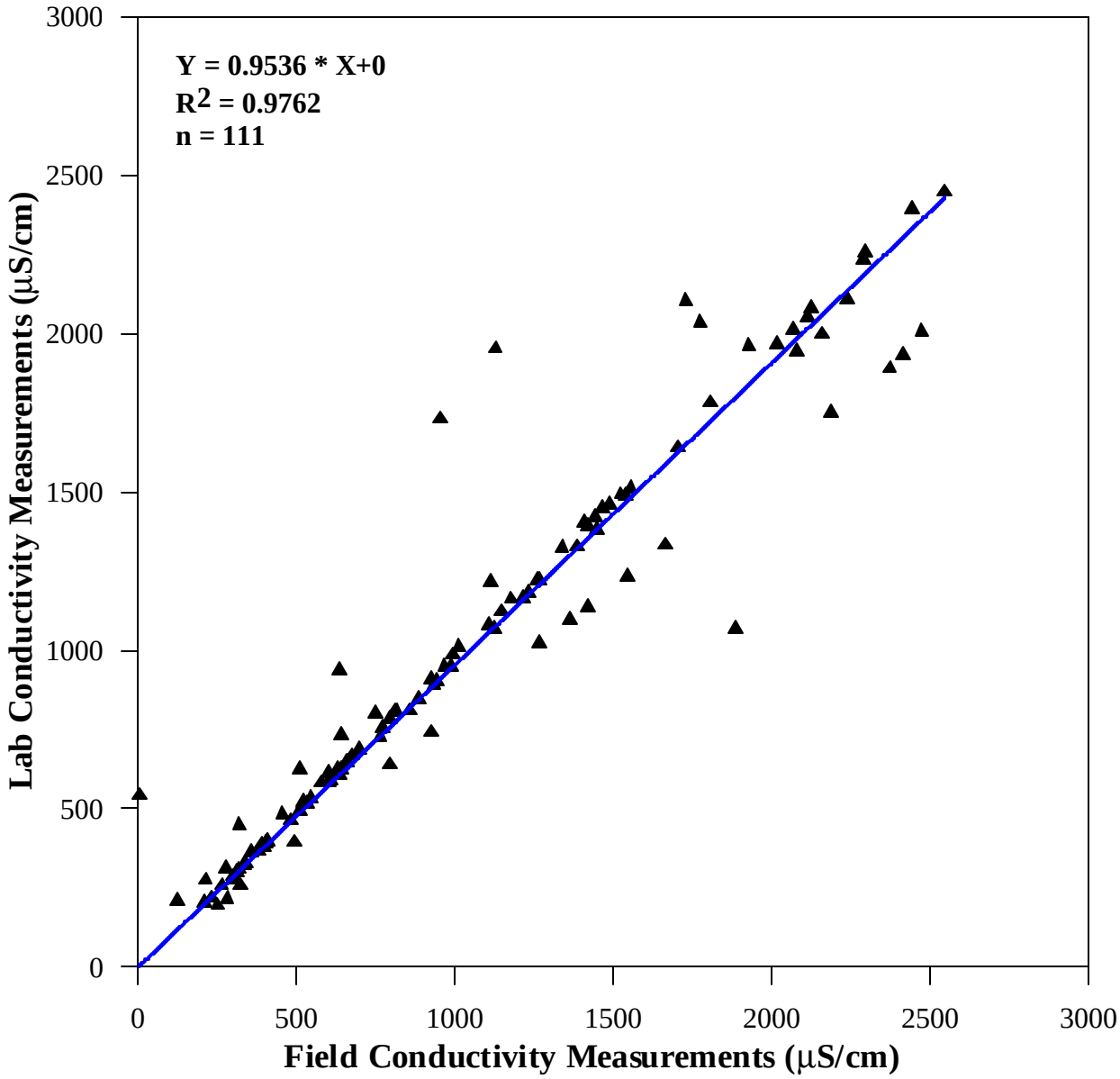


Figure 15. Lab measurements vs. field measurements of reanalyzed conductivity outlier samples.

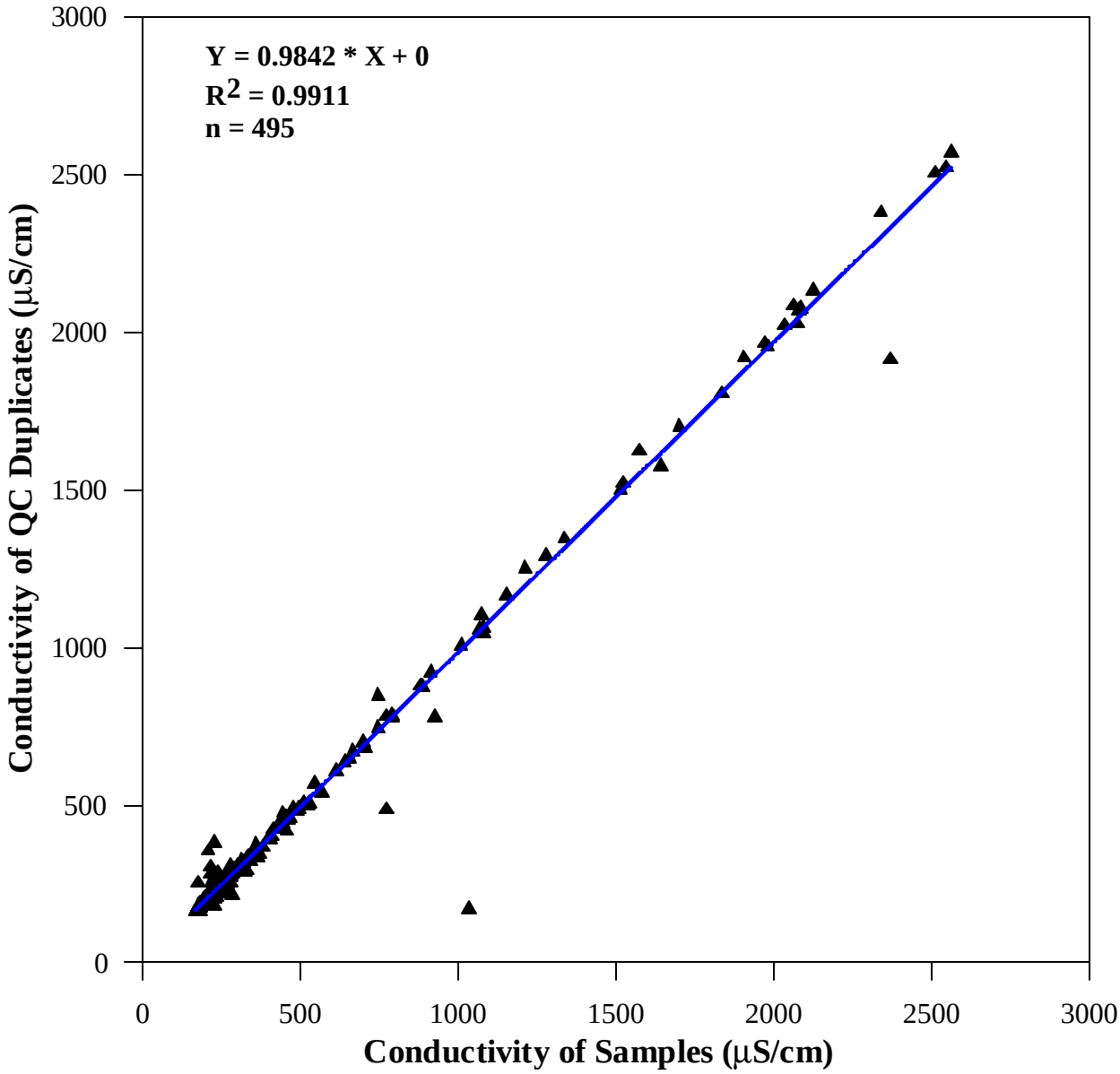
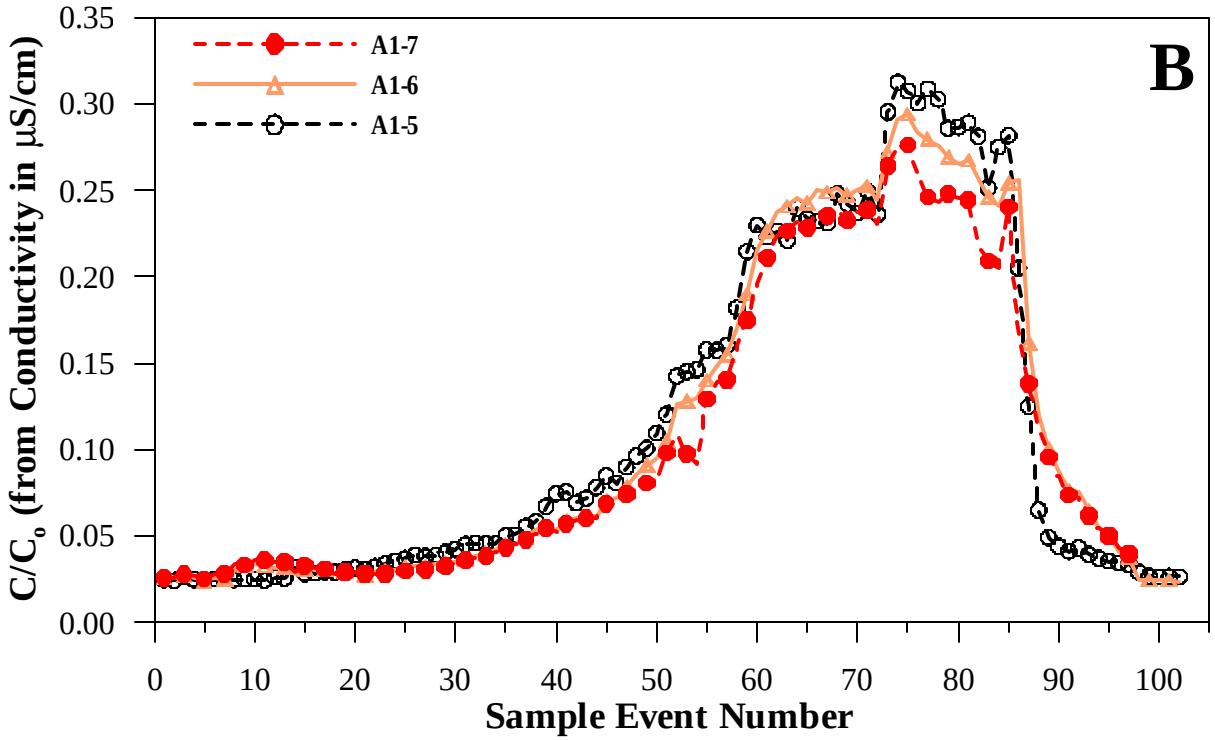


Figure 16. Conductivity QC duplicates: 495 measurements from the field and laboratory.



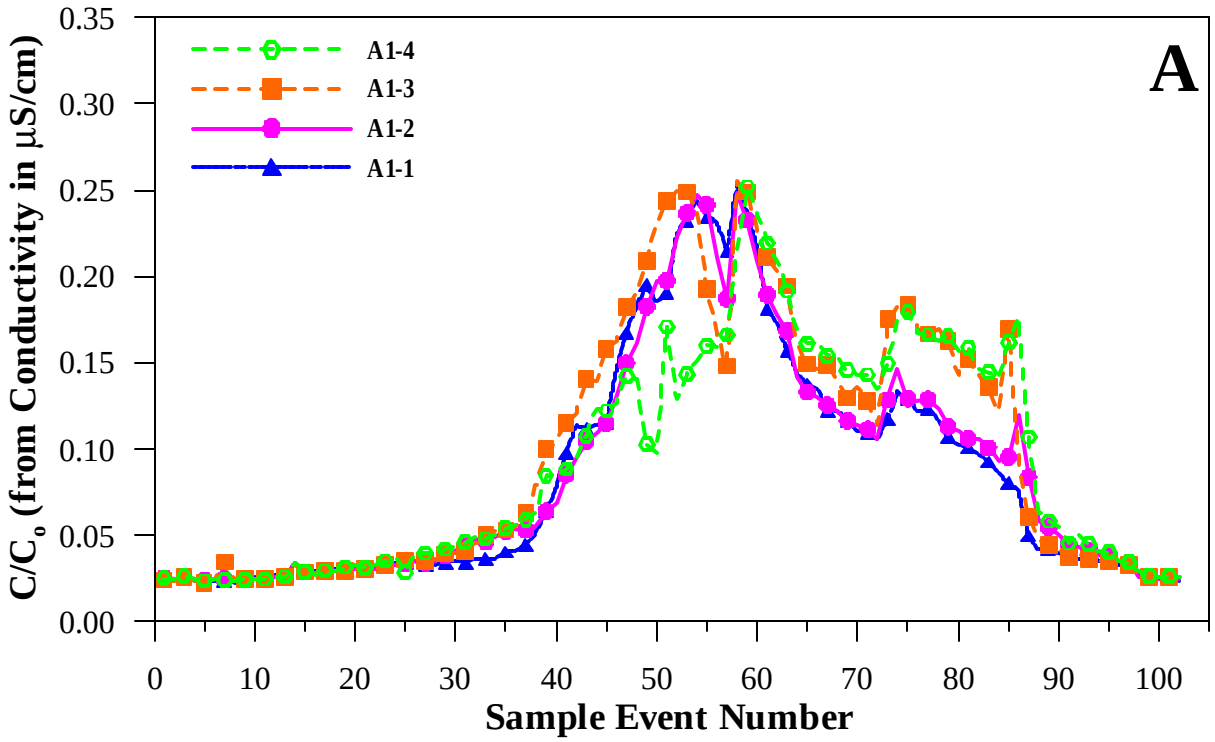


Figure 17. Breakthrough curves (adjusted for outliers) for conductivity in well A1.
A. Zones 1-4. B. Zones 5-7. C. Zones 8-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

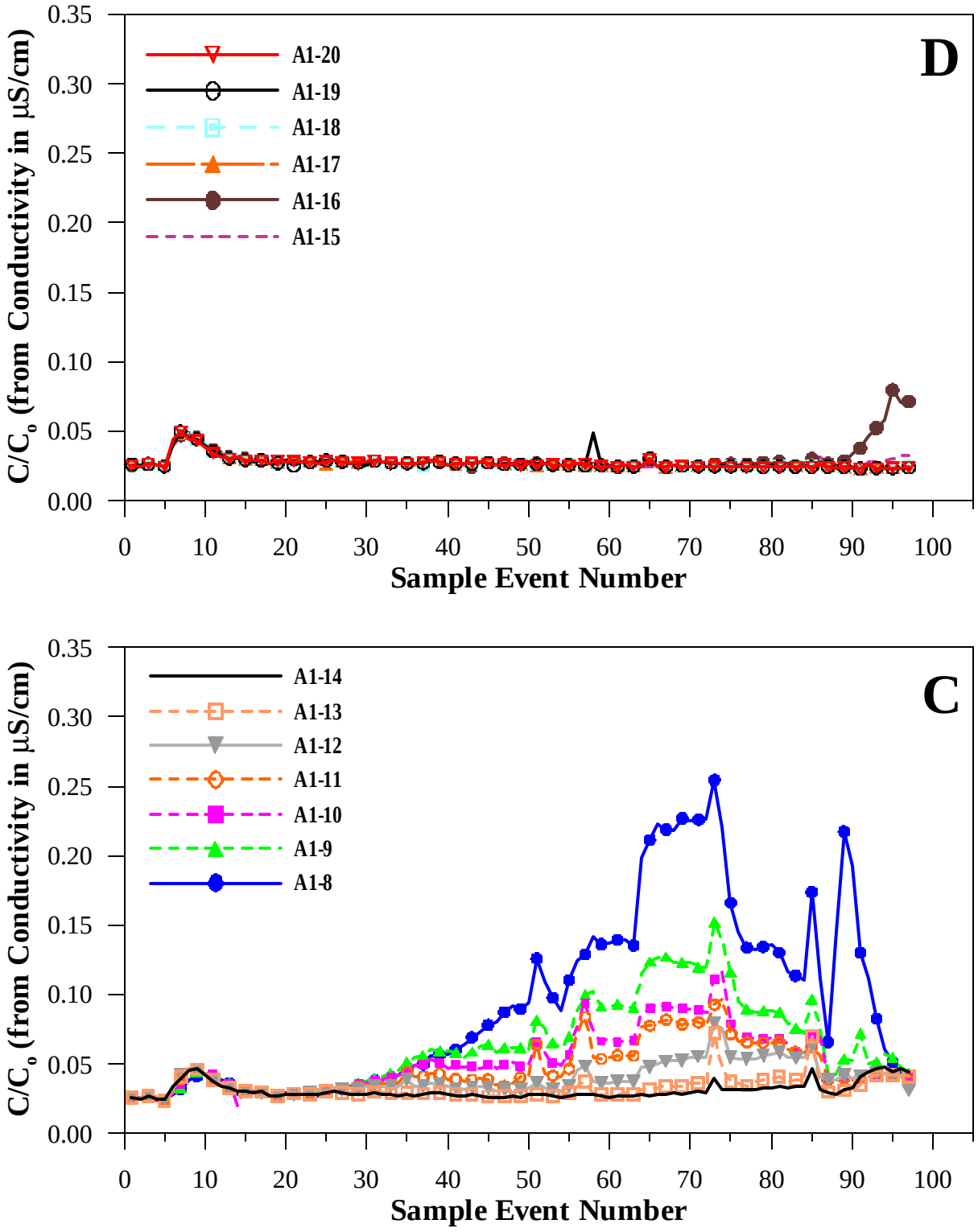


Figure 17. Breakthrough curves (adjusted for outliers) for conductivity in well A1.
A. Zones 1-4. B. Zones 5-7. C. Zones 8-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

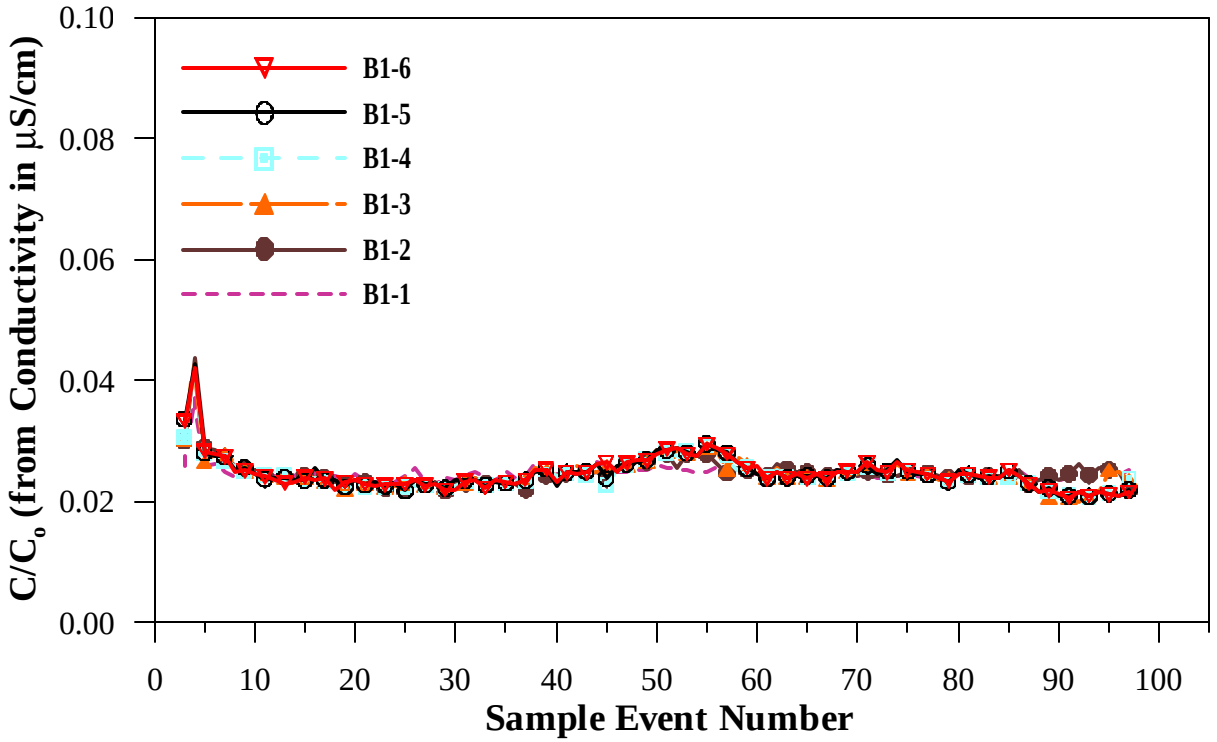


Figure 18. Breakthrough curves for conductivity in well B1.

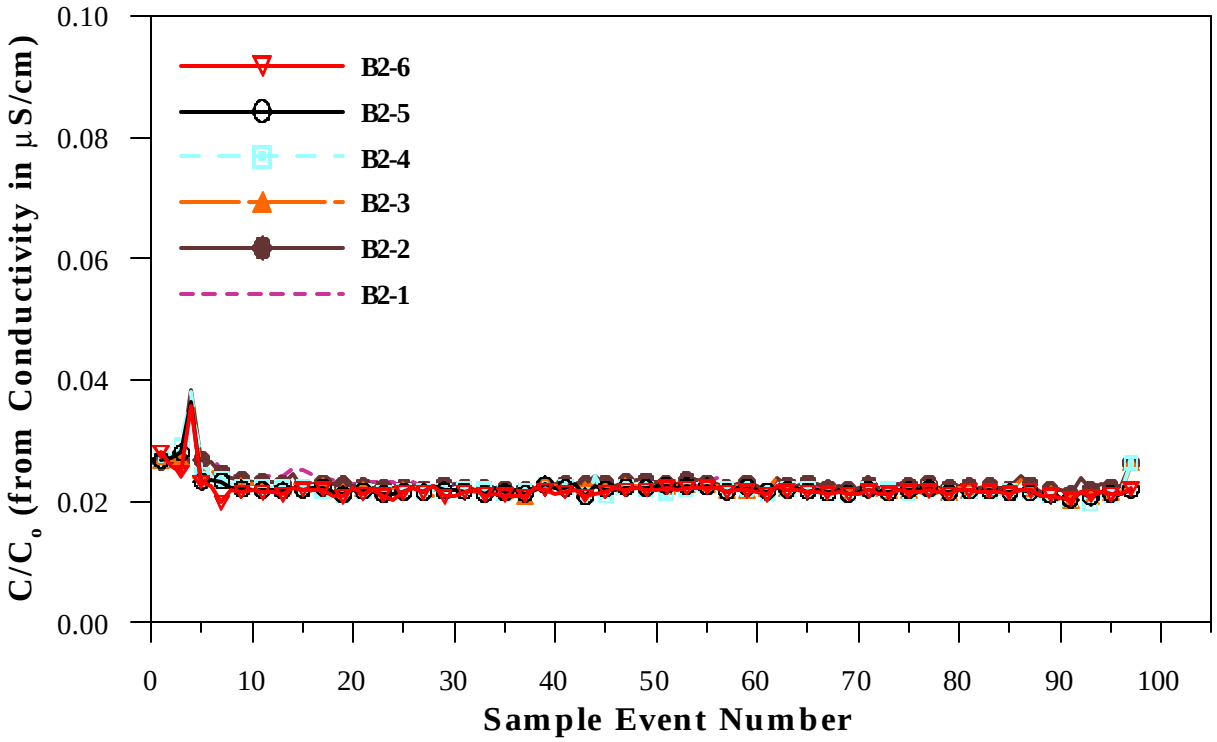


Figure 19. Breakthrough curves for conductivity in well B2.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

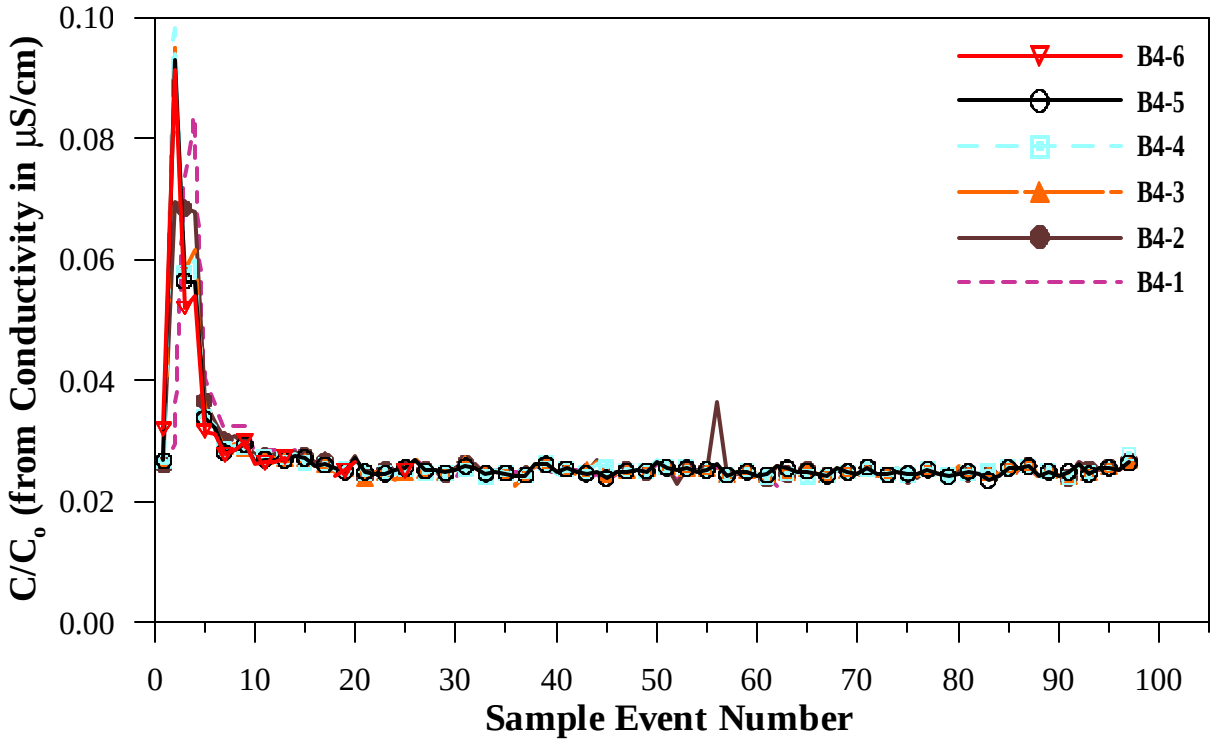


Figure 20. Breakthrough curves for conductivity in well B4.

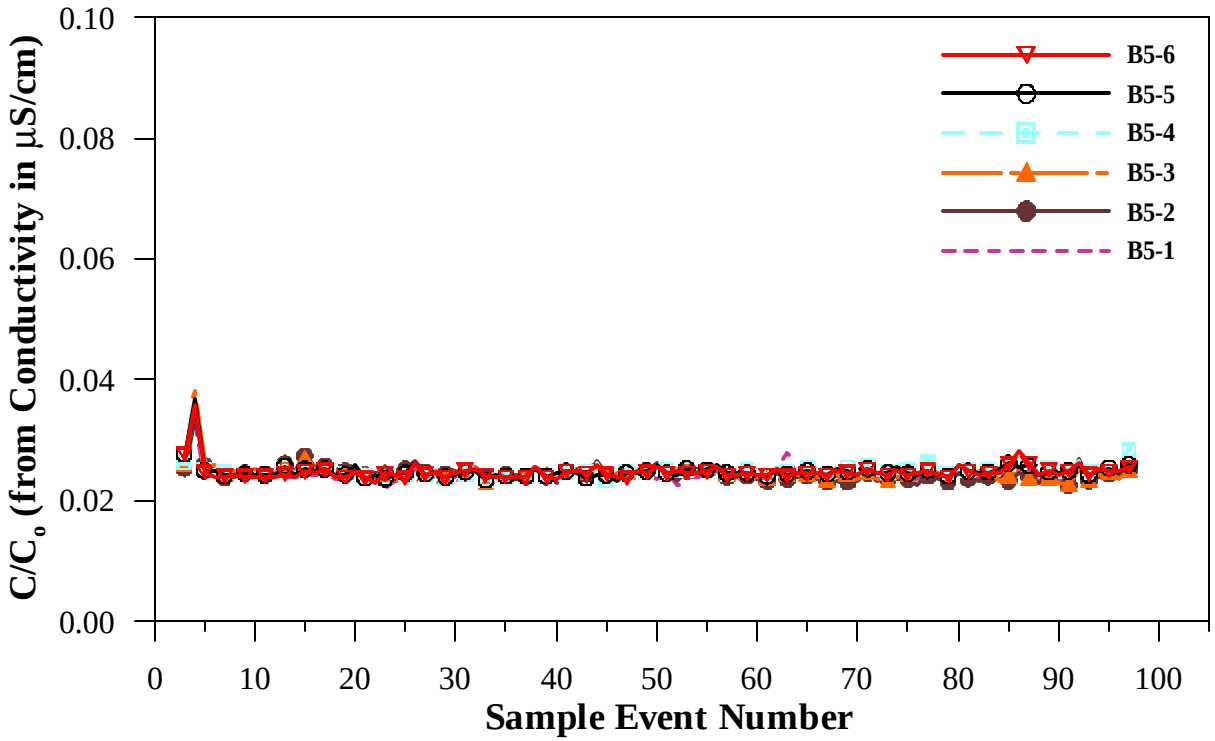


Figure 21. Breakthrough curves for conductivity in well B5.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

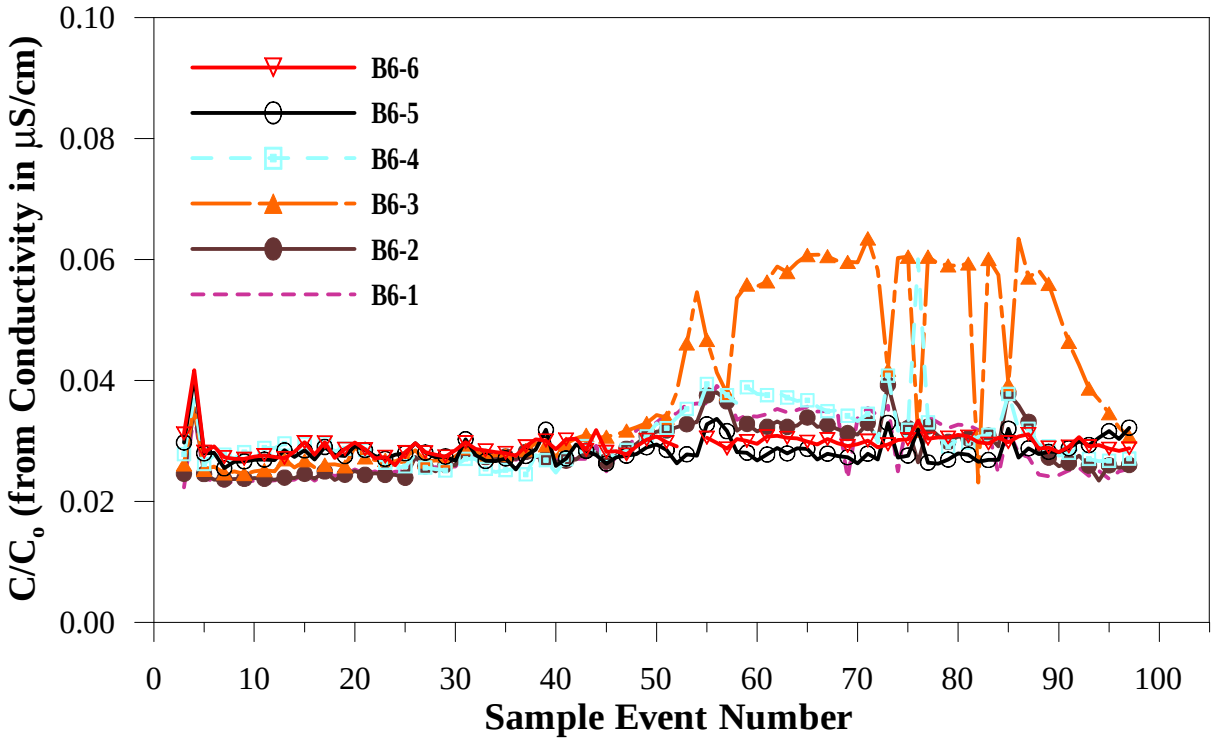


Figure 22. Breakthrough curves for conductivity in withdrawal well B6.

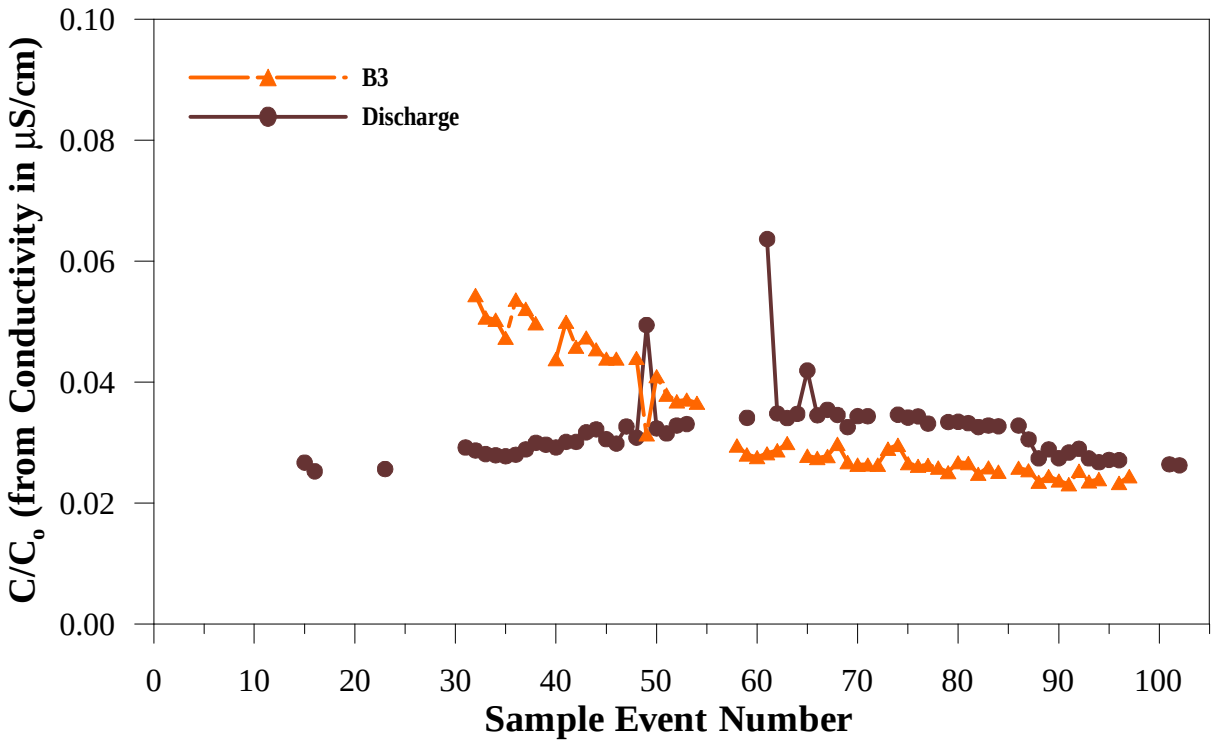


Figure 23. Breakthrough curves for conductivity in injection well B3 after the straddle packer was removed, and from the discharge line.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

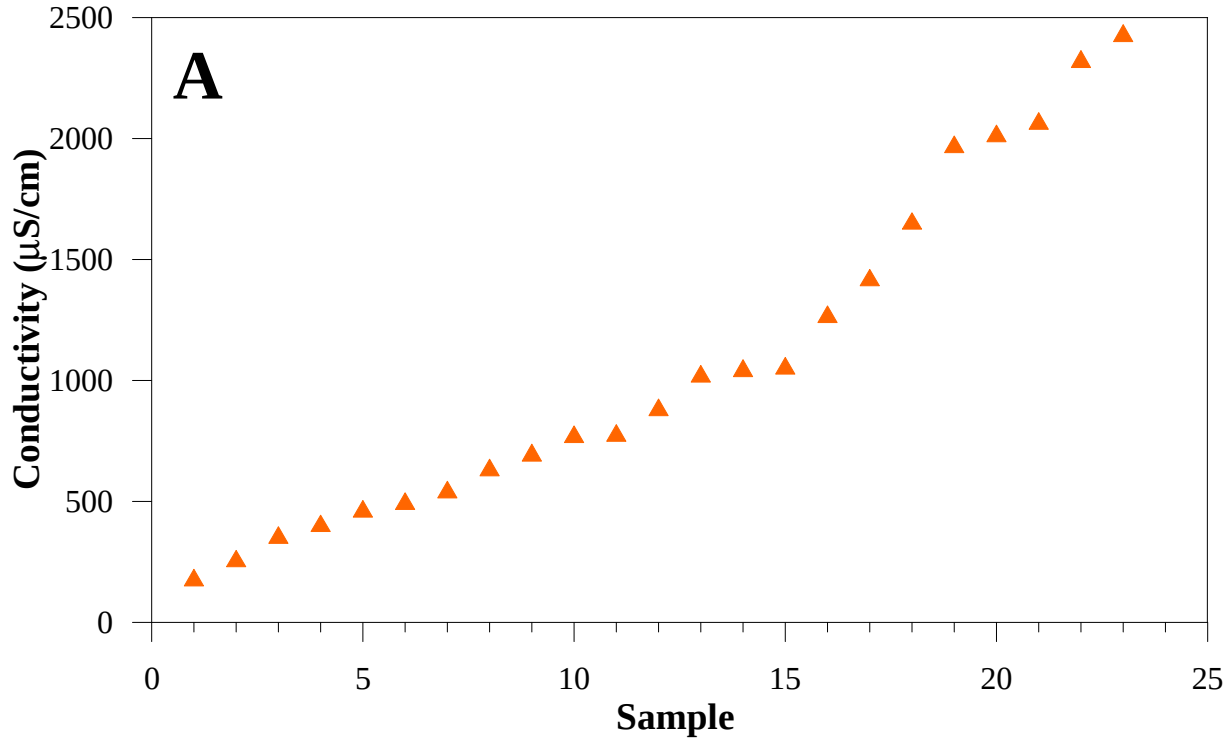


Figure 24A. Samples selected for determination of conductivity-bromide relationship.

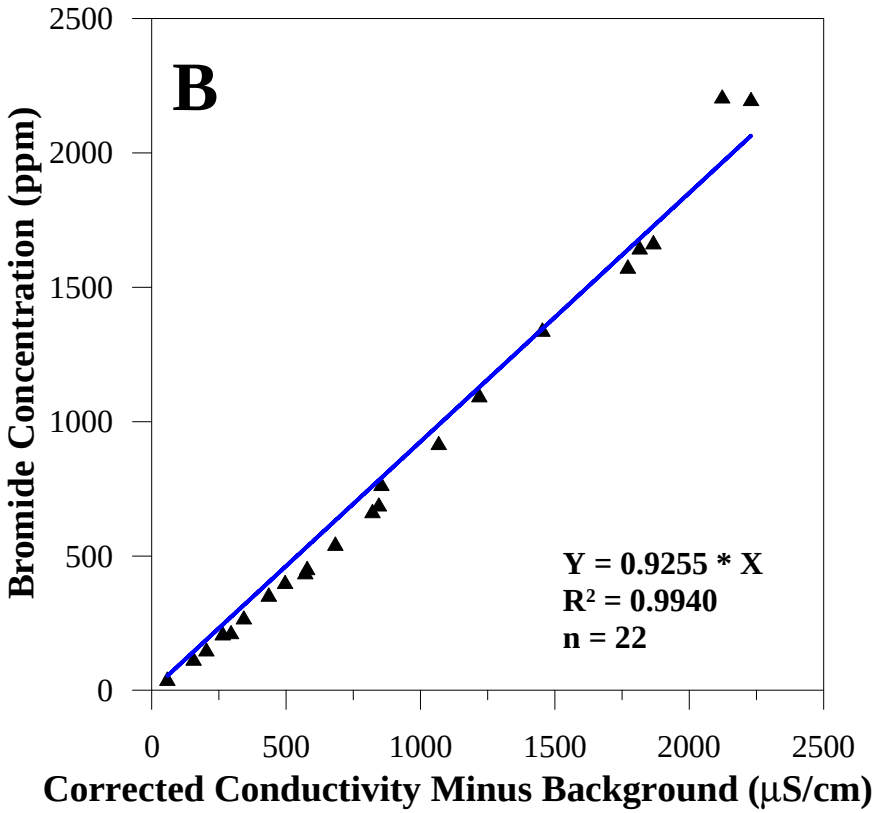


Figure 24B. Bromide vs. conductivity relationship.

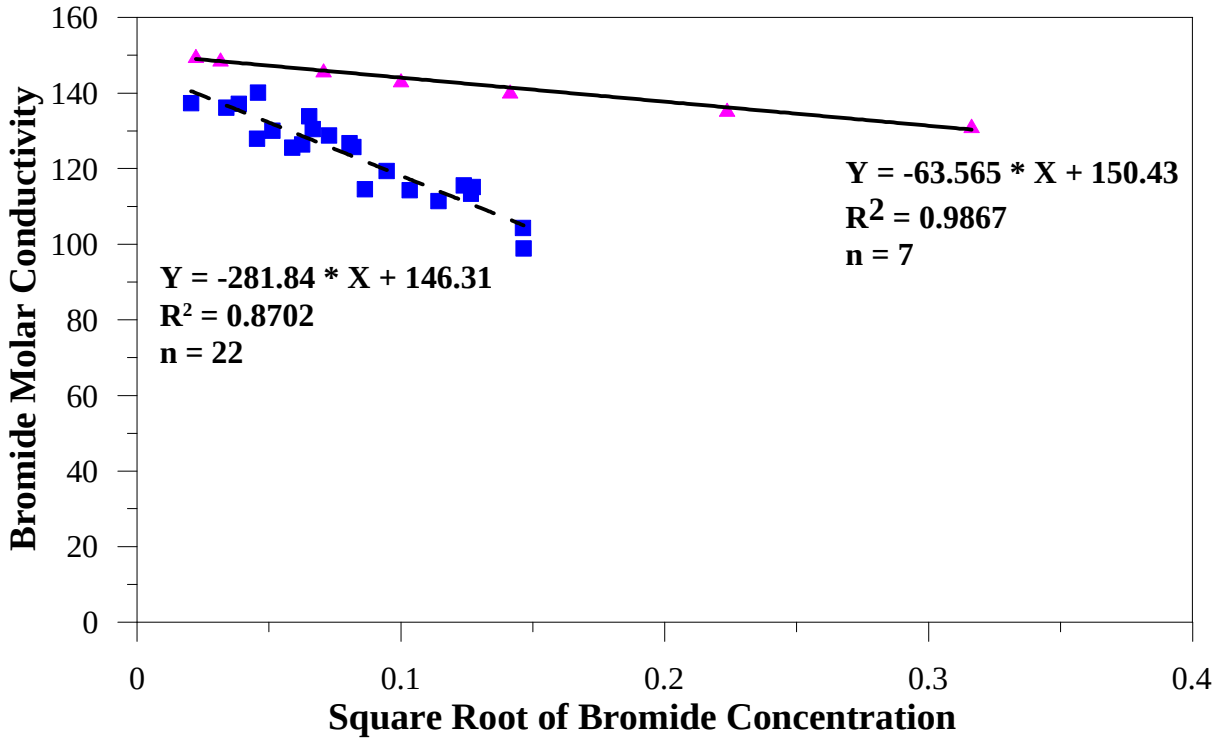


Figure 25. Plot of bromide molar conductivity vs. square root of bromide concentration.

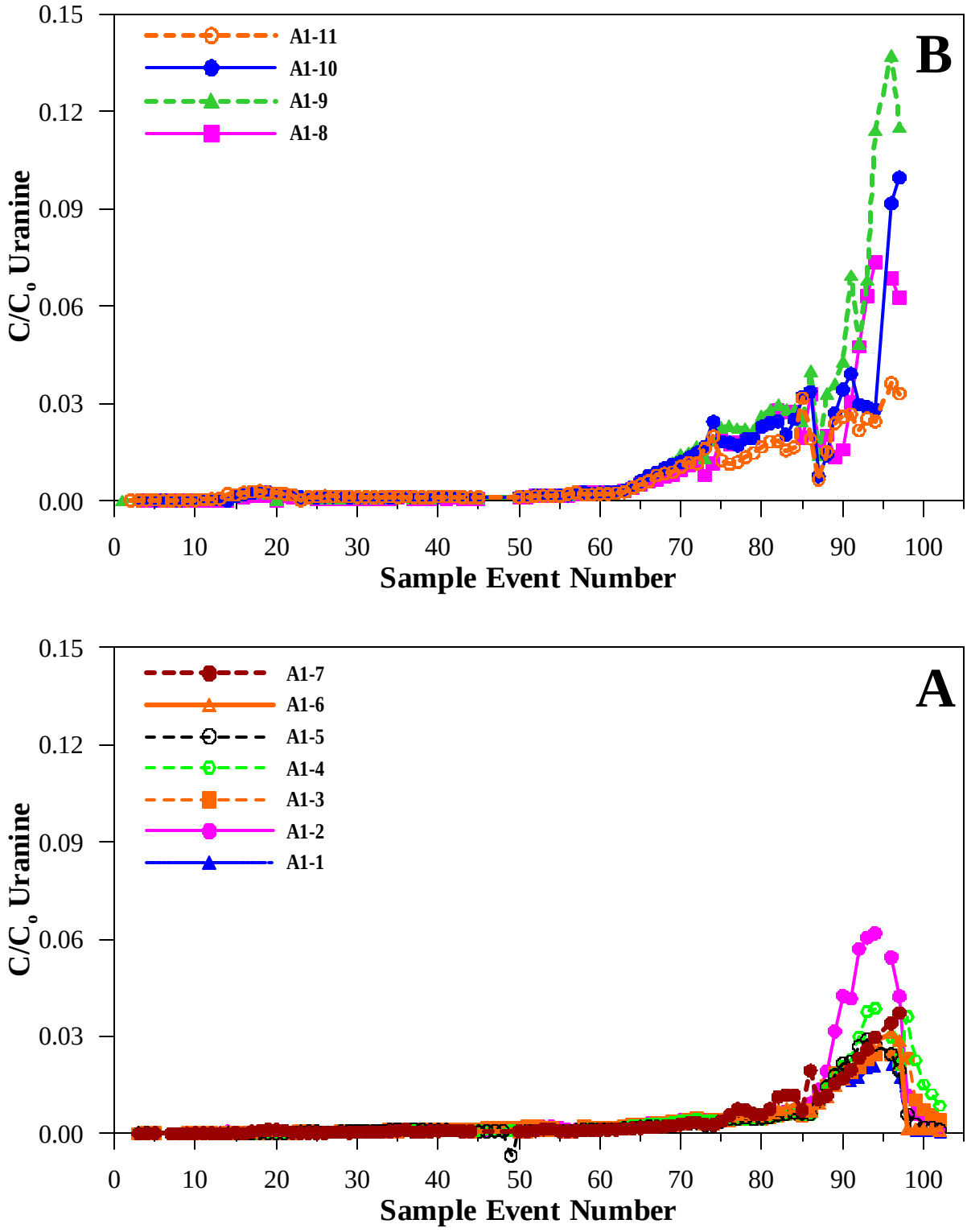
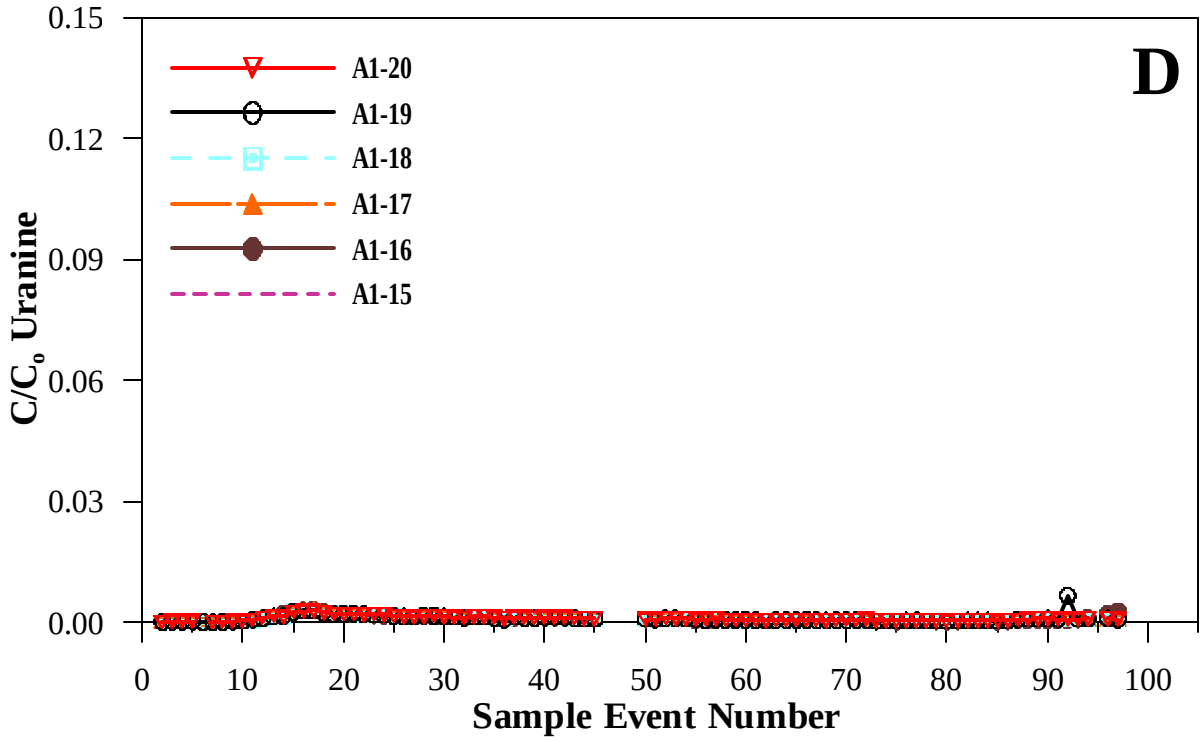


Figure 26. Breakthrough curves for uranine in well A1.
A. Zones 1-7. B. Zones 8-11. C. Zones 12-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.



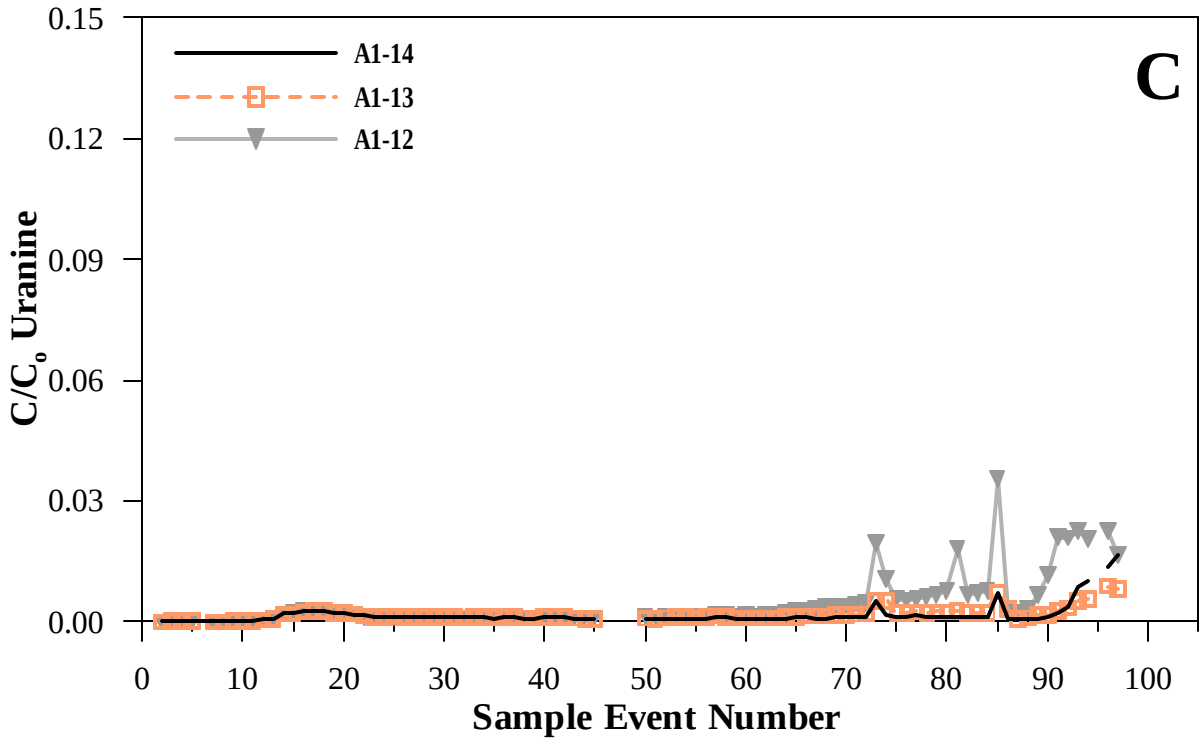


Figure 26. Breakthrough curves for uranine in well A1.
A. Zones 1-7. B. Zones 8-11. C. Zones 12-14. D. Zones 15-20.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

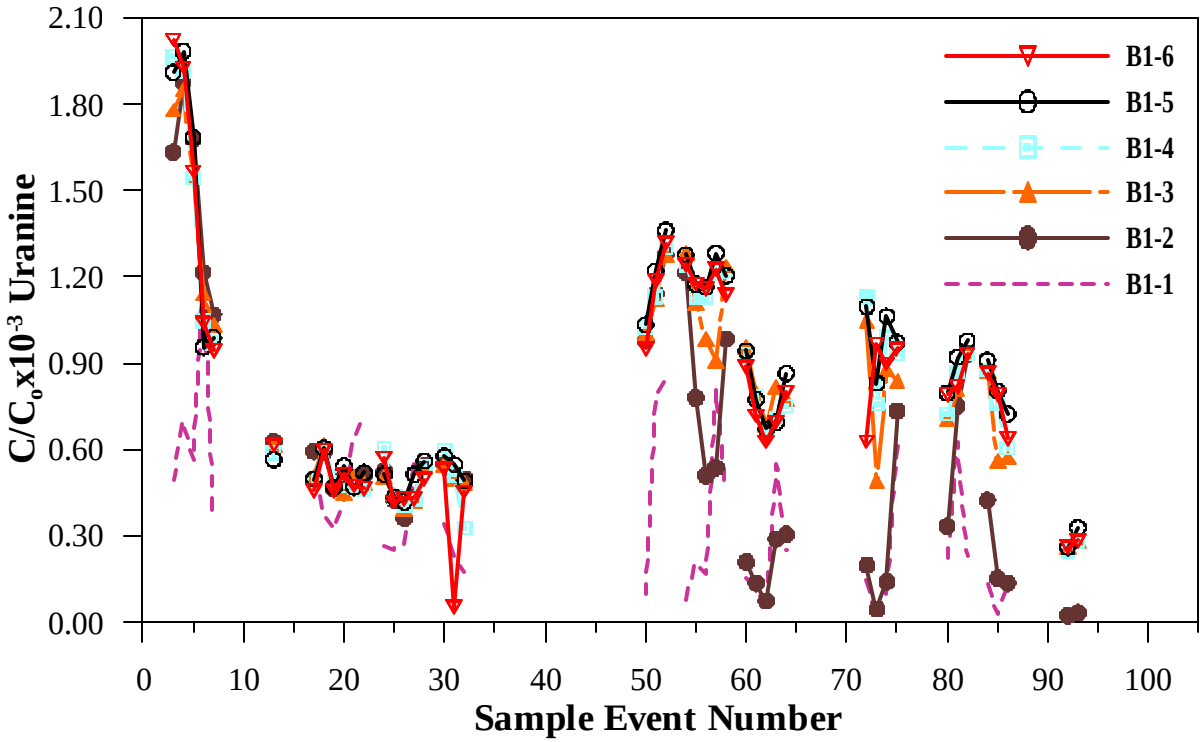


Figure 27. Breakthrough curves for uranine in well B1.

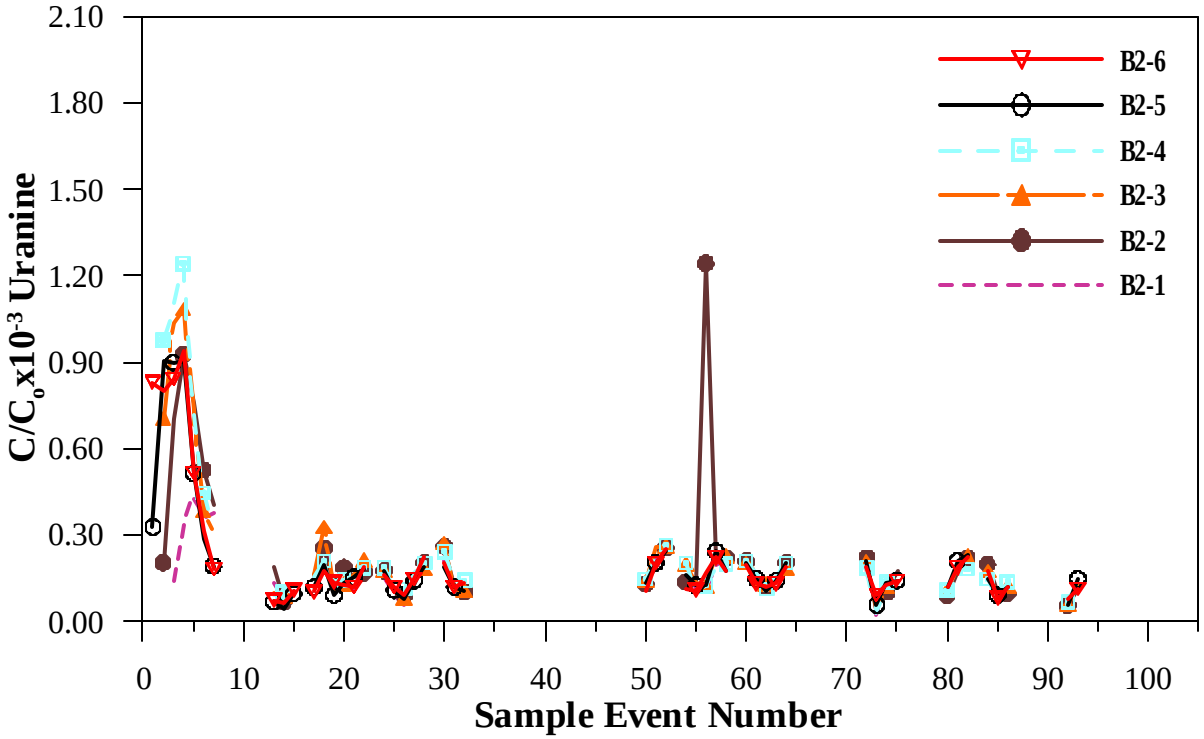


Figure 28. Breakthrough curves for uranine in well B2.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

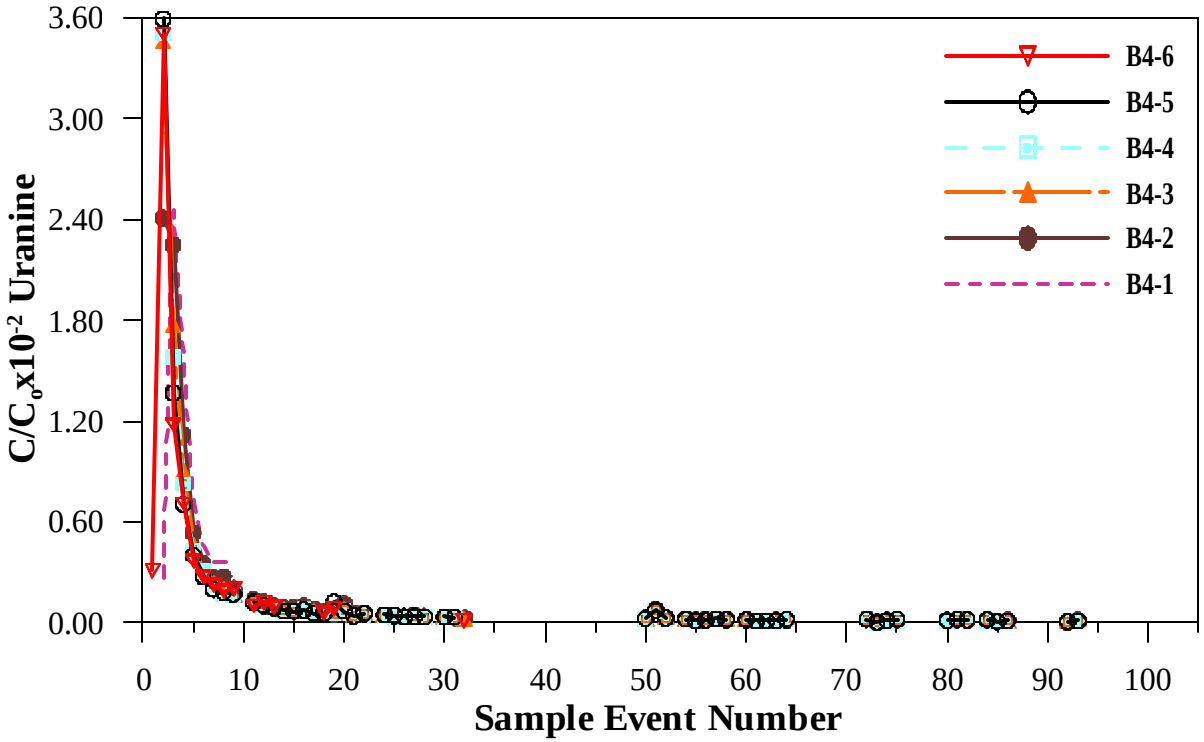


Figure 29. Breakthrough curves for uranine in well B4.

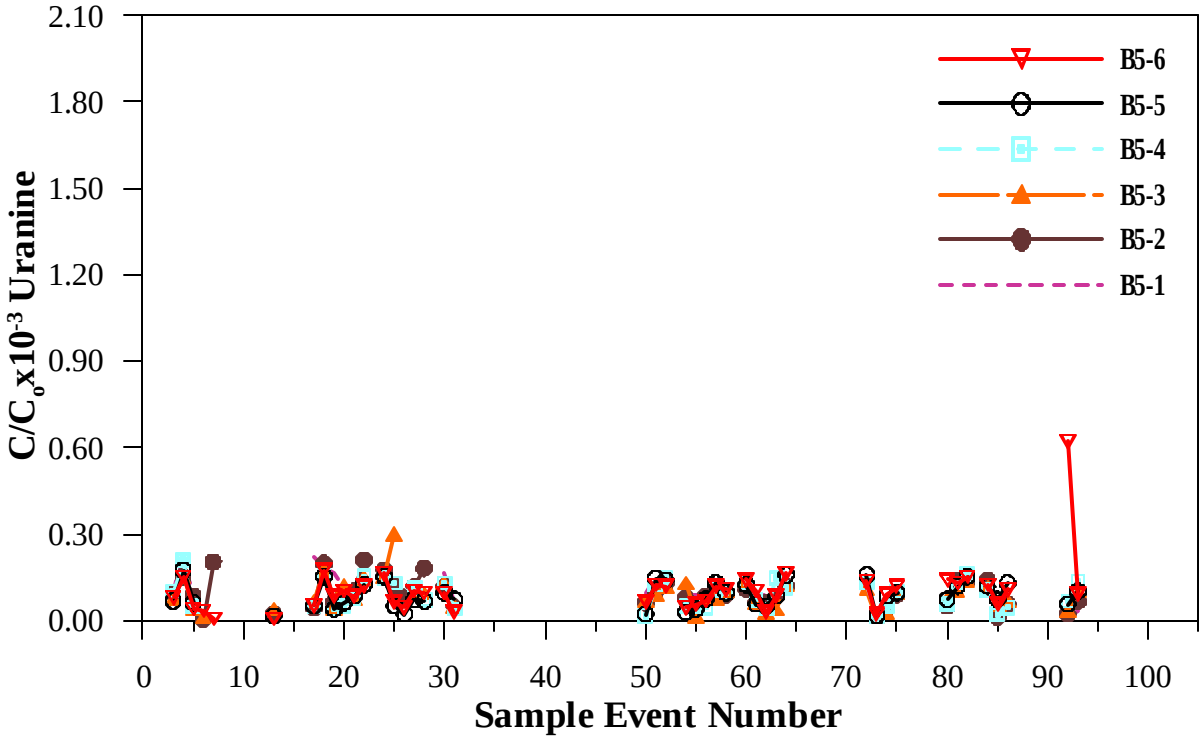


Figure 30. Breakthrough curves for uranine in well B5.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

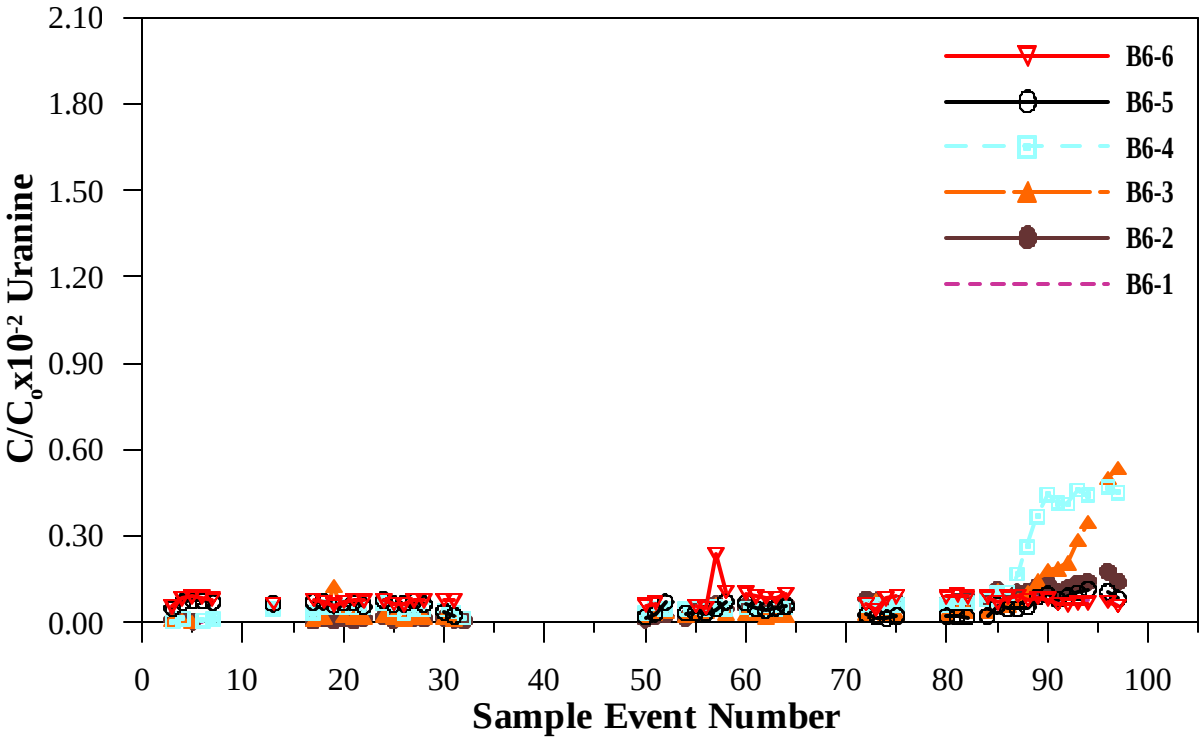


Figure 31. Breakthrough curves for uranine in withdrawal well B6.

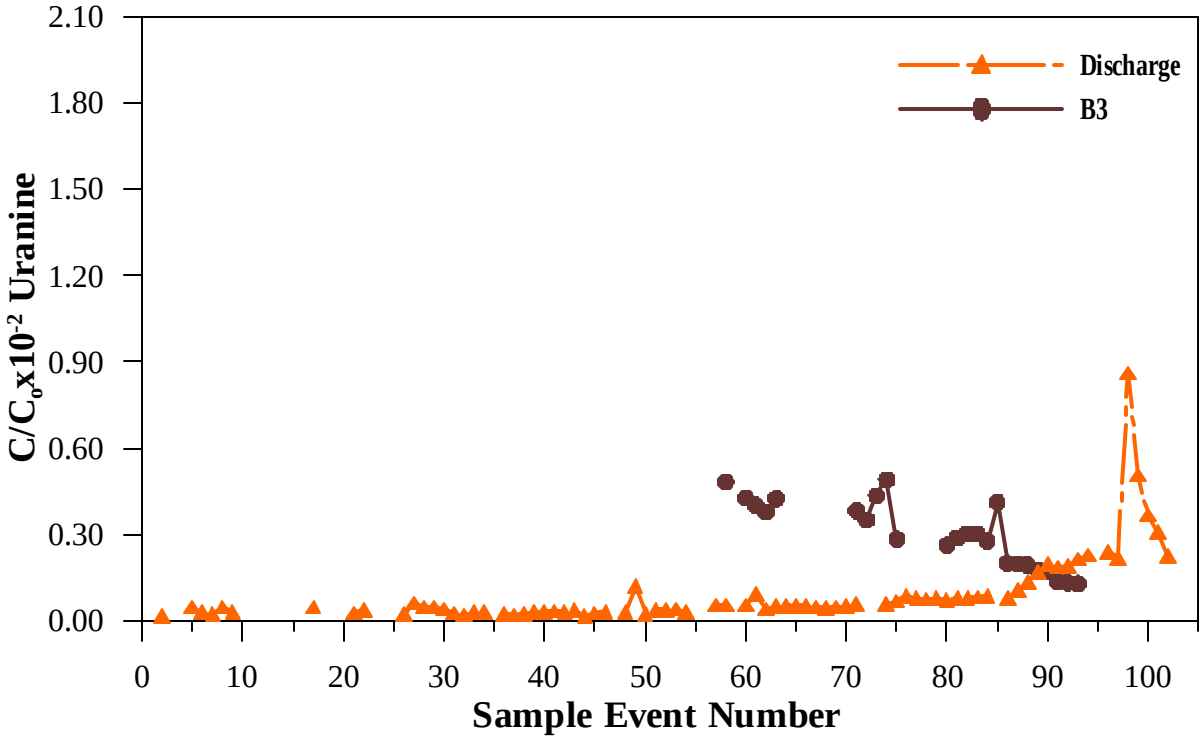


Figure 32. Breakthrough curves for uranine in injection well B3 after the straddle packer was removed, and from the discharge line.

Note: Sampling events generally occur every 4 hours. See Appendix 2.

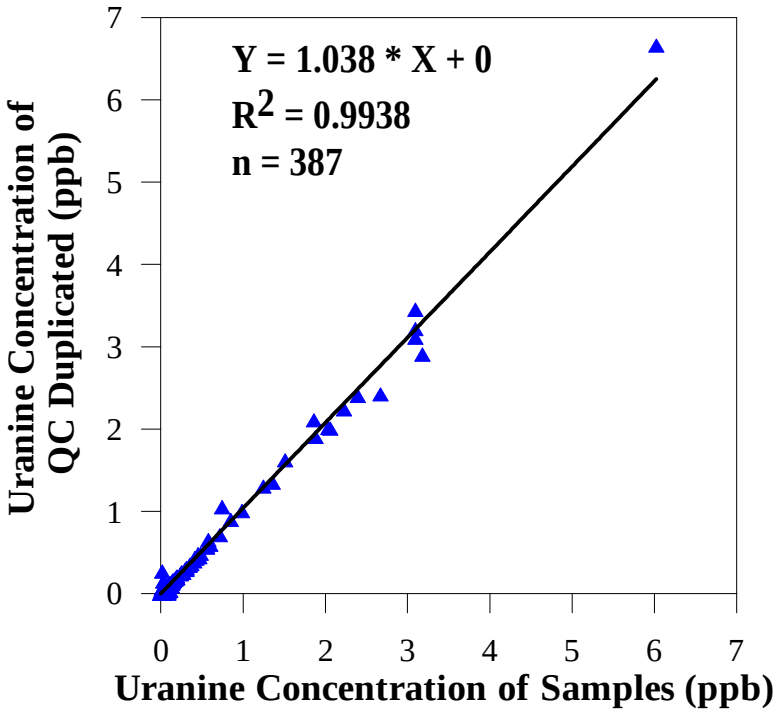


Figure 33. Comparison of 387 pairs of uranine concentration (fluorescence) measurements for samples and duplicates collected during the TTLT.

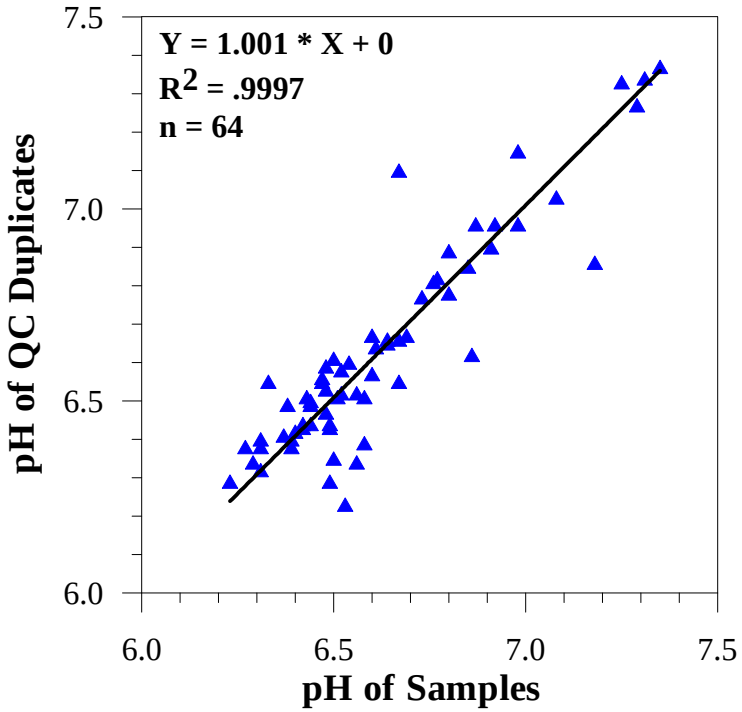


Figure 34. Comparison of 64 pairs of pH measurements for samples and duplicates collected during the TTLT.

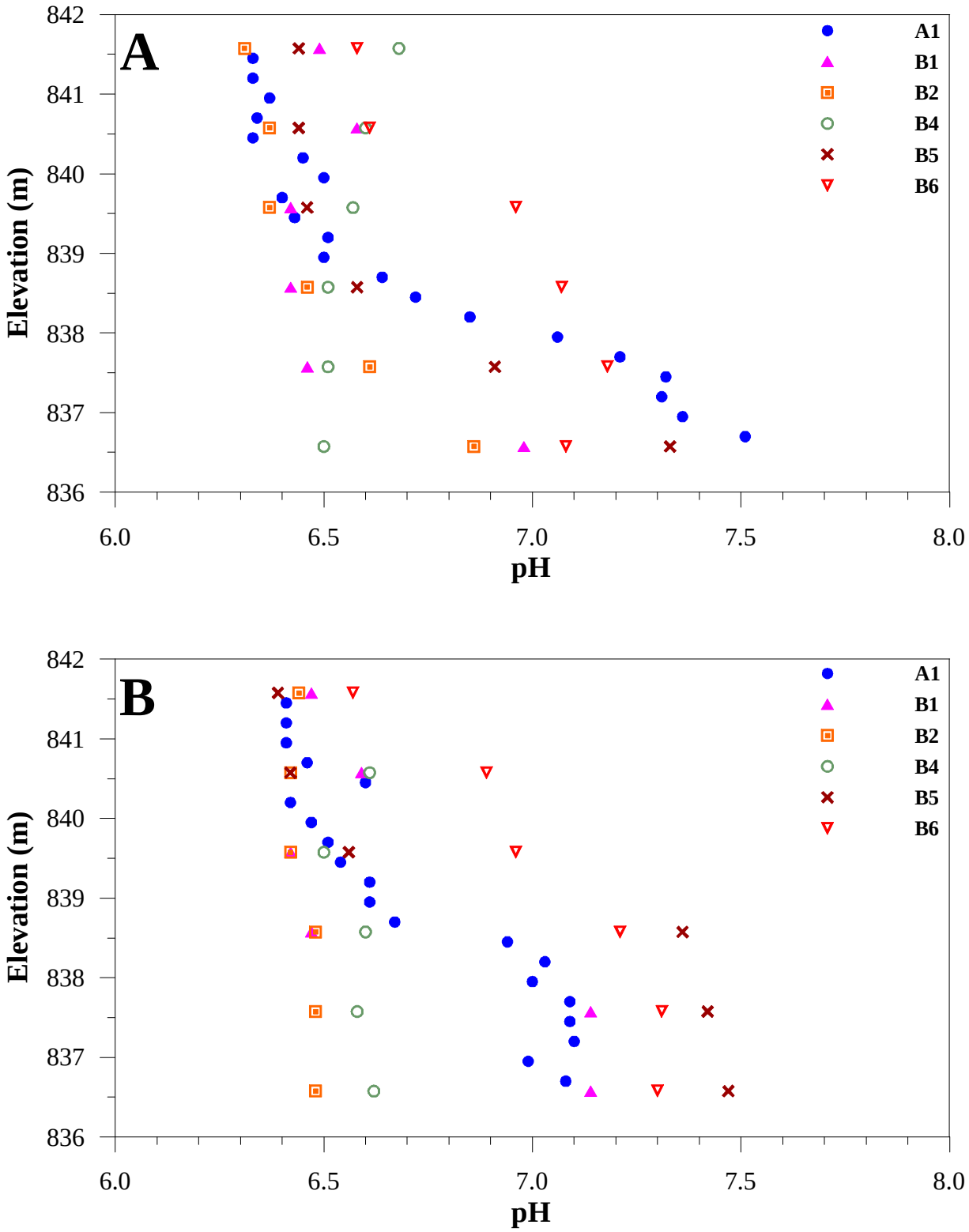


Figure 35. Typical pH profiles. A. Event 5. B. Event 93.

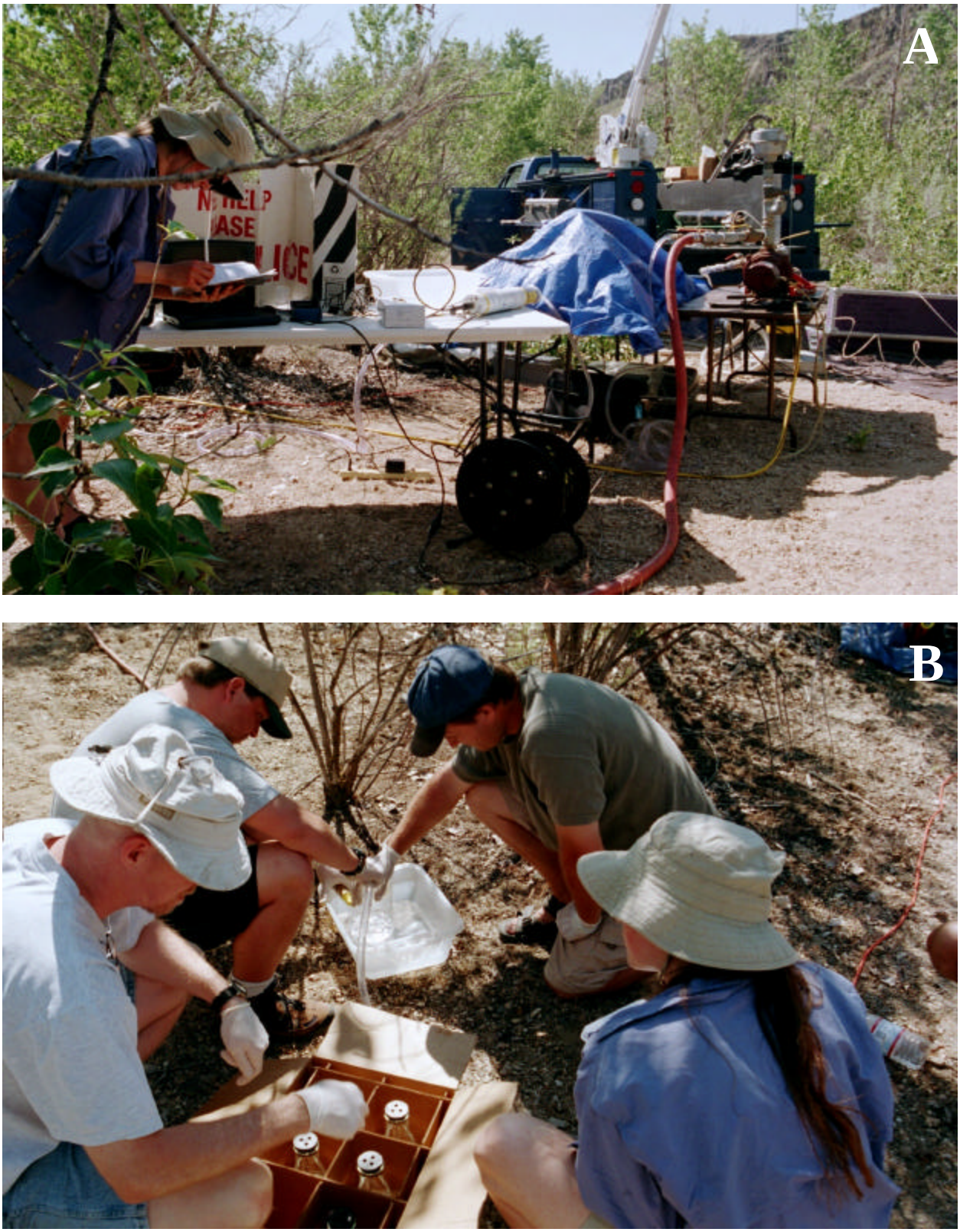


Figure 36. A. Photograph of measurement of water-quality parameters during purging prior to collection of water samples for microbiological analysis. B. Photograph of collection of water samples for microbiological analysis.

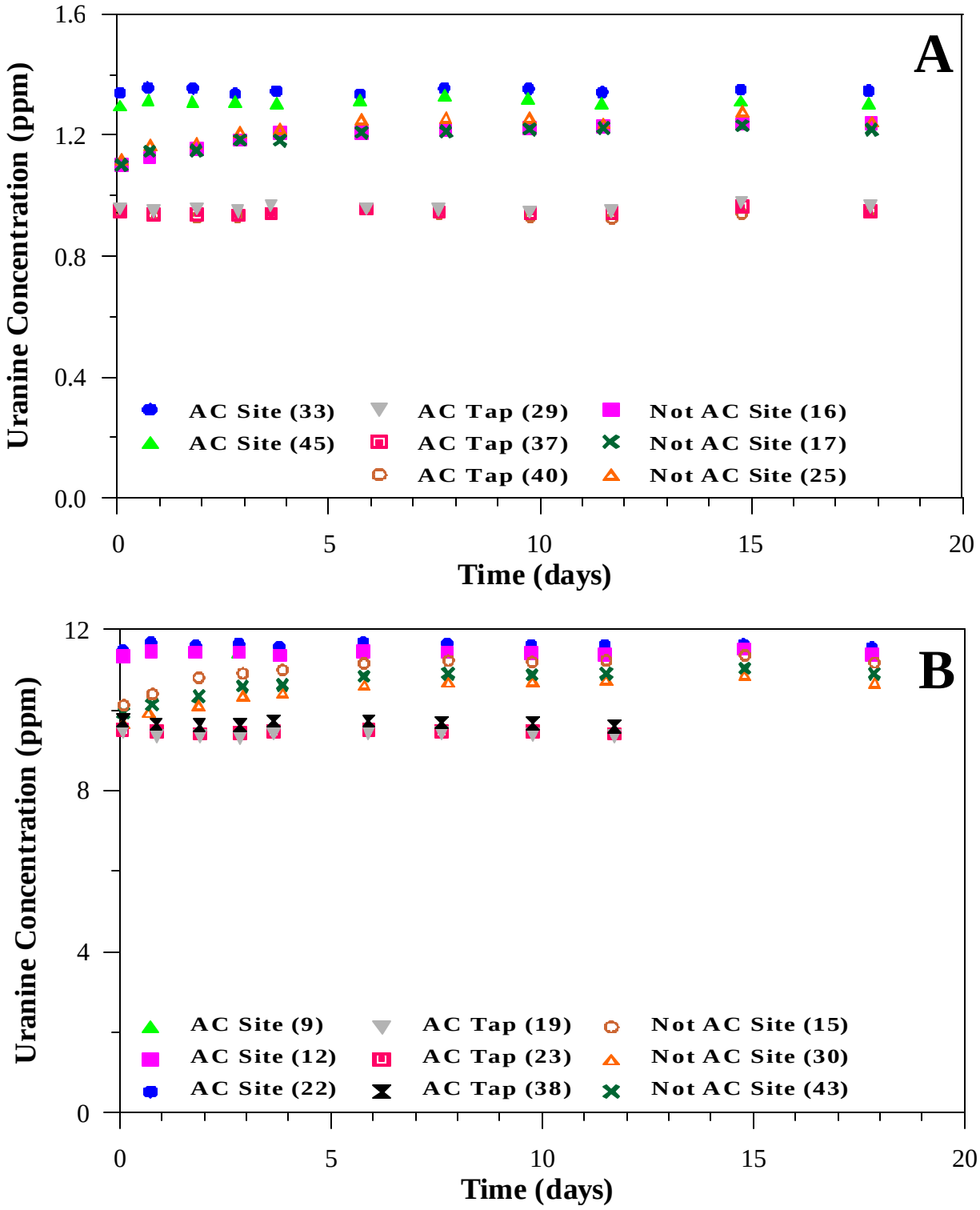
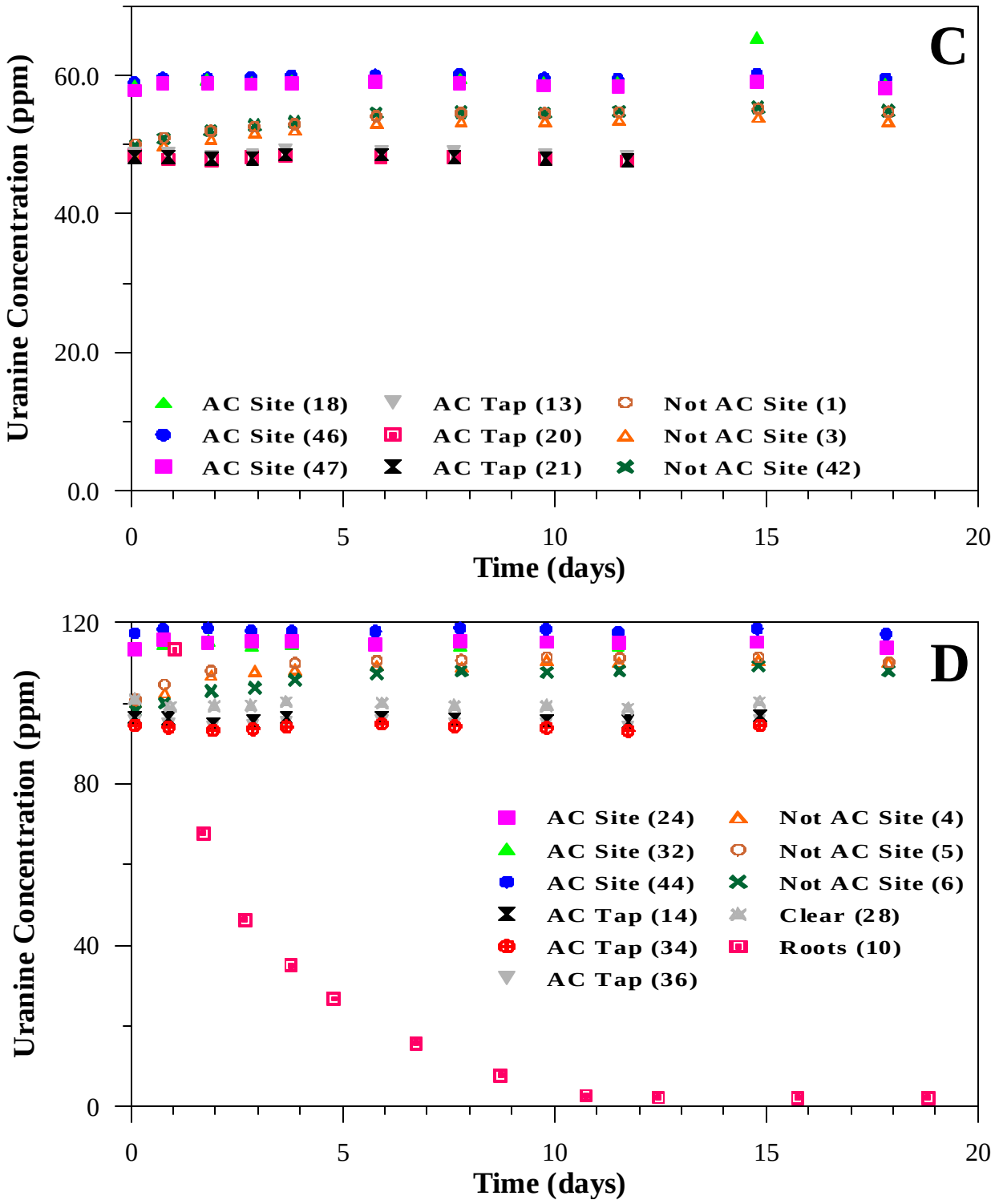


Figure 37. Changes in uranine concentration or fluorescence with time in microbiological experiment. AC samples were autoclaved. Site samples used water from BHRS. Tap samples used Boise city water. Number in parenthesis is random number of sample beaker.
A. 1 ppb uranine. B. 10 ppb uranine. C. 50 ppb uranine. D. 100 ppb uranine and including a sample with cottonwood roots.



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A. 1 ppb uranine. B. 10 ppb uranine. C. 50 ppb uranine. D. 100 ppb uranine and including a sample with cottonwood roots.

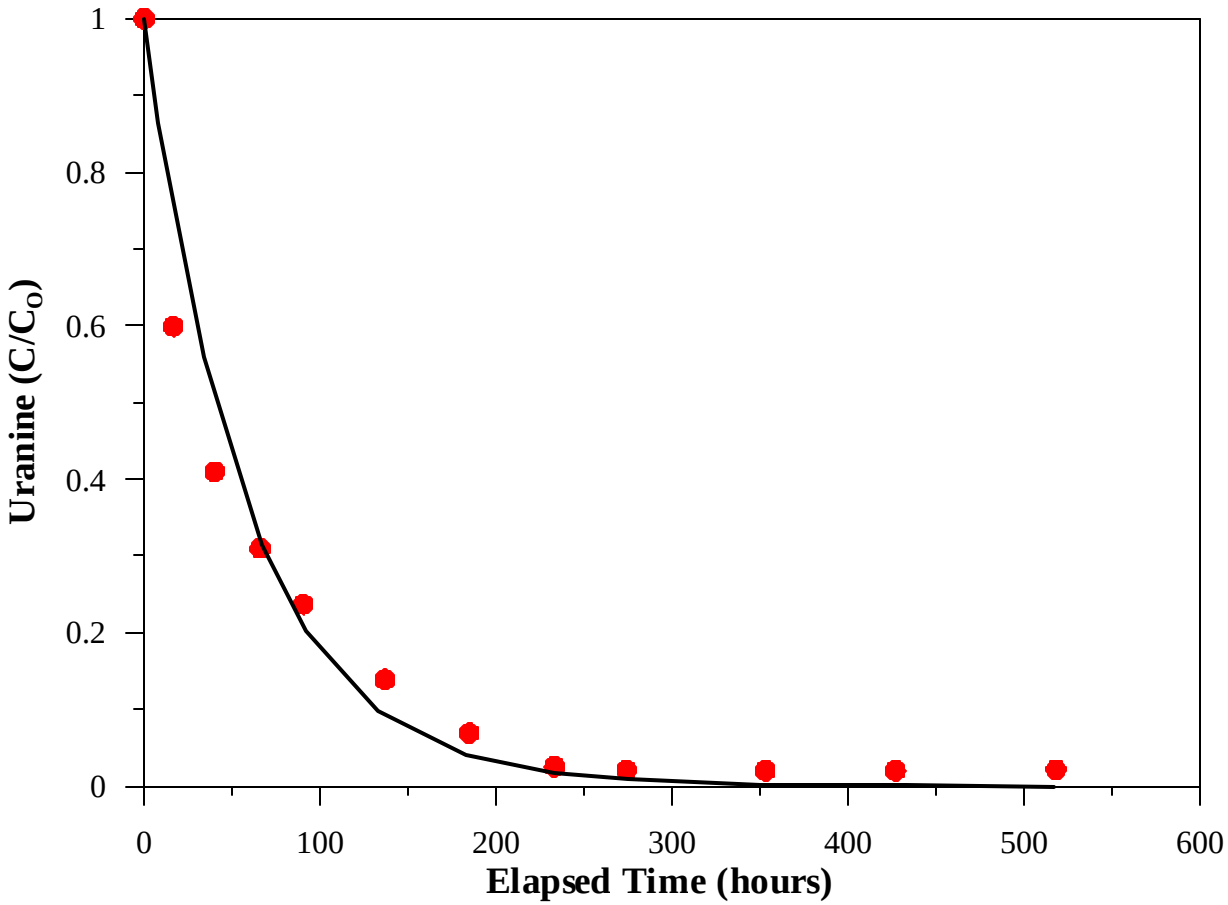

Figure 38. First-order reaction kinetics ($k=1.8x10^{-2}$ hr^{-1}) fit to uranine concentration changes during the experiment to test for biological interaction.

Appendix 1. Tracer/Time-Lapse Test chronology: July 29-August 18, 2001

Month/Day	Military Time	Event
7/29	0730	measure C and X wells
	1132	start recording background in PST8 (note river level drop)
	1500	start recording in X wells, measure X wells
	~1600	peristaltic pumps at ~10-20 ml/min
	1804	stop recording PST8
7/30	0700	measure C and X wells
	0948	start recording new background in PST8
	1750	set up fiber-optic transducer system, start recording at 5 min interval
7/31	1630	pump from X2 (16.5-17 gpm) to top off 1000 gal water tank (pump ~20 min)
	1735	stop background recording in PST8
	1738	stop background in fiber-optic transducer system
	~1745	set straddle packer in B3
	~1808	start practice injection test
	~1832	stop practice injection test
	2028	pump with low-flow-rate sample pump from X1 for site water
	2040	stop collecting from practice injection test with PST8
	2105	start recording with PST8; transducer added to B3 upper zone
	2115	stop recording with fiber-optic transducer system
	2128	start recording with fiber-optic transducer system
8/01	0725	stop recording with fiber-optic transducer system
	0725	add flowmeter to fiber-optic data logging system
	0728	start recording with fiber-optic transducer system (same settings)
	0730 to 0830	extract files from in-well loggers in X wells, start recording again
	0730 to 0830	measure X wells
	0930	start filling tank from well X2, add tracers, mix
	1015	tank water temperature is 14.8 °C
	1030	stop filling tank
	1115	tank water temperature is 16.3 °C
	1122	stop mixing
	1128	start priming
	1139	start recording straddle packer data
	1140	start injecting into target zone in B3 *elapsed time for test = 0*
	1213	stop injecting after 33 min and 20 sec; water temperature is 19.8 C
	1248	start pumping from B6 at ~5 gpm
	1320	remove transducer from C2 (it was disturbing radar tomography)
	1530	decrease pumping rate at B6 from ~5.25-5.3 gpm to ~5 gpm
	1600	readjust pumping rate at B6

Appendix 1. Tracer/Time-Lapse Test chronology: July 29-August 18, 2001 (continued)

Month/Day	Military Time	Event
8/02	0830	decrease pumping rate at B6 from ~5.35 to 5 gpm
	1215	peristaltic pumps: turn down from 30 to 15
	1500	peristaltic pumps: turn down from 15 to 5
8/03	1620	put transducer back in C2
	~1630	peristaltic pumps: turn up from 5 to 30
	~1730	peristaltic pumps: turn down to 5
8/04	1200	measure C and X wells
	~1430	peristaltic pumps: turn up from 5 to 30
	~1530	peristaltic pumps: turn down to 5
	~1830	peristaltic pumps: turn up from 5 to 30
	~1930	peristaltic pumps: turn down to 5
8/05	~0500	peristaltic pumps: turn up from 5 to 30
	~0600	peristaltic pumps: turn down to 5
	~1430	peristaltic pumps: turn up from 5 to 30
	~1530	peristaltic pumps: turn down to 5
	~1830	peristaltic pumps: turn up from 5 to 30
	~1930	peristaltic pumps: turn down to 5
8/06	~0630	peristaltic pumps: turn up from 5 to 30
	~0730	peristaltic pumps: turn down to 5
	~1030	peristaltic pumps: turn up from 5 to 30
	~1130	peristaltic pumps: turn down to 5
		replace B4-6 with B3 at B4-B5 peristaltic pump
	~1500	peristaltic pumps: turn up from 5 to 30
	~1700	peristaltic pumps: turn down to 5
	1715	measure C and X wells
8/07	~0700	power failure, PST8 stopped ~0700
	1036	restart fiber-optic transducer system with straddle packer and atmospheric pressure transducers added
	1103	restart PST8
	1343	stop pumping at B6, small pump quit
	1400	start pumping at B6, use red pump
	1050	measure A, B, C and X wells
	~2010	generator out, stop pumping at B6
	~2017	start red pump again
8/08	1315	measure C and X wells

Appendix 1. Tracer/Time-Lapse Test chronology: July 29-August 18, 2001 (continued)

Month/Day	Military Time	Event
8/09	1215	measure C and X wells
8/10	~0900	remove packers from B3
	1000	stop pump, start B3-B6 tomography
	1315	measure A, B, C and X wells
	1930	start pump after tomography
8/11	0225	peristaltic pumps: turn up to 30
8/12	1345	measure C and X wells
8/13	0710	stop pump, start B3-B6 tomography
	~1345	start pump after tomography
	1610	measure C and X wells
8/14	2140	tripped valve, pumping rate spike to 15 gpm at B6 for ~30 sec
8/15	0700	stop pump, start B3-B6 tomography
	1400	start red pump at 26 +/- 1 gpm in B6 after tomography
	~1415	move discharge point to slough NE of X1
	~1430	peristaltic pumps: down to 10 ml/min
	1445	measure C and X wells
8/16	1720	stop recording in PST8
8/17	12-1400	remove in-well loggers from X wells
	~1400	radar tomography completed, pull A1 and B6, put B6 string in A1
	~1600	start pumping from A1 at ~26 gpm

Appendix 2. Sample events

Event	Date	Time (hr:min)	Elapsed time (hr:min)	Elapsed time (min)	Elapsed time (days)
Background	7/31	15:00	-20:40	-1240	
Background	8/1	7:00	-4:40	-280	
Injection	8/1	11:40	0:00	0	0.
1	8/1	13:00	1:20	80	0.55556
2	8/1	16:00	4:20	260	0.18056
3	8/1	20:00	8:20	500	0.34722
4	8/2	0:14	12:34	754	0.52361
5	8/2	6:30	18:50	1130	0.78472
6	8/2	11:00	23:20	1400	0.97222
7	8/2	15:00	27:20	1640	1.13889
8	8/2	19:00	31:20	1880	1.30556
9	8/2	22:00	34:20	2060	1.43056
10	8/3	1:00	37:20	2240	1.55556
11	8/3	4:00	40:20	2420	1.68056
12	8/3	7:00	43:20	2600	1.80556
13	8/3	10:00	46:20	2780	1.93056
14	8/3	14:00	50:20	3020	2.09722
15	8/3	17:00	53:20	3200	2.22222
16	8/3	20:00	56:20	3380	2.34722
17	8/3	23:00	59:20	3560	2.47222
18	8/4	7:00	67:20	4040	2.80556
19	8/4	11:00	71:20	4280	2.97222
20	8/4	15:00	75:20	4520	3.13889
21	8/4	19:00	79:20	4760	3.30556
22	8/4	23:00	83:20	5000	3.47222
23	8/5	3:00	87:20	5240	3.63889
24	8/5	7:00	91:20	5480	3.80556
25	8/5	11:00	95:20	5720	3.97222
26	8/5	15:00	99:20	5960	4.13889
27	8/5	19:00	103:20	6200	4.30556
28	8/5	23:00	107:20	6440	4.47222
29	8/6	3:00	111:20	6680	4.63889
30	8/6	7:00	115:20	6920	4.80556
31	8/6	11:00	119:20	7160	4.97222
32	8/6	15:00	123:20	7400	5.13889
33	8/6	19:00	127:20	7640	5.30556
34	8/6	23:00	131:20	7880	5.47222
35	8/7	4:00	136:20	8180	5.68056
36	8/7	7:00	139:20	8360	5.80556

Appendix 2. Sample events (continued)

Event	Date	Time (hr:min)	Elapsed time (hr:min)	Elapsed time (min)	Elapsed time (days)
37	8/7	11:00	143:20	8600	5.97222
38	8/7	15:00	147:20	8840	6.13889
39	8/7	19:00	151:20	9080	6.30556
40	8/7	23:00	155:20	9320	6.47222
41	8/8	3:00	159:20	9560	6.63889
42	8/8	7:00	163:20	9800	6.80556
43	8/8	11:00	167:20	10040	6.97222
44	8/8	15:00	171:20	10280	7.13889
45	8/8	19:00	175:20	10520	7.30556
46	8/8	23:00	179:20	10760	7.47222
47	8/9	3:00	183:20	11000	7.63889
48	8/9	7:00	187:20	11240	7.80556
49	8/9	11:00	191:20	11480	7.97222
50	8/9	15:00	195:20	11720	8.13889
51	8/9	19:00	199:20	11960	8.30556
52	8/9	23:00	203:20	12200	8.47222
53	8/10	3:00	207:20	12440	8.63889
54	8/10	7:00	211:20	12680	8.80556
55	8/10	11:00	215:20	12920	8.97222
56	8/10	15:00	219:20	13160	9.13889
57	8/10	19:00	223:20	13400	9.30556
58	8/10	23:00	227:20	13640	9.47222
59	8/11	3:00	231:20	13880	9.63889
60	8/11	7:00	235:20	14120	9.80556
61	8/11	11:00	239:20	14360	9.97222
62	8/11	15:00	243:20	14600	10.13889
63	8/11	19:00	247:20	14840	10.30556
64	8/11	23:00	251:20	15080	10.47222
65	8/12	3:00	255:20	15320	10.63889
66	8/12	7:00	259:20	15560	10.80556
67	8/12	11:00	263:20	15800	10.97222
68	8/12	15:00	267:20	16040	11.13889
69	8/12	19:00	271:20	16280	11.30556
70	8/12	23:00	275:20	16520	11.47222
71	8/13	3:00	279:20	16760	11.63889
72	8/13	7:00	283:20	17000	11.80556
73	8/13	11:00	287:20	17240	11.97222
74	8/13	15:00	291:20	17480	12.13889
75	8/13	19:00	295:20	17720	12.30556

Appendix 2. Sample events (continued)

Event	Date	Time (hr:min)	Elapsed time (hr:min)	Elapsed time (min)	Elapsed time (days)
76	8/13	23:00	299:20	17960	12.47222
77	8/14	3:00	303:20	18200	12.63889
78	8/14	7:00	307:20	18440	12.80556
79	8/14	11:00	311:20	18680	12.97222
80	8/14	15:00	315:20	18920	13.13889
81	8/14	19:00	319:20	19160	13.30556
82	8/14	23:00	323:20	19400	13.47222
83	8/15	3:00	327:20	19640	13.63889
84	8/15	7:00	331:20	19880	13.80556
85	8/15	11:00	335:20	20120	13.97222
86	8/15	15:00	339:20	20360	14.13889
87	8/15	19:00	343:20	20600	14.30556
88	8/15	23:00	347:20	20840	14.47222
89	8/16	3:00	351:20	21080	14.63889
90	8/16	7:00	355:20	21320	14.80556
91	8/16	11:00	359:20	21560	14.97222
92	8/16	15:00	363:20	21800	15.13889
93	8/16	19:00	367:20	22040	15.30556
94	8/16	23:00	371:20	22280	15.47222
95	8/17	3:00	375:20	22520	15.63889
96	8/17	7:00	379:20	22760	15.80556
97	8/17	11:00	383:20	23000	15.97222
98	8/17	19:00	391:20	23480	16.30556
99	8/17	23:00	395:20	23720	16.47222
100	8/18	3:00	399:20	23960	16.63889
101	8/18	7:00	403:20	24200	16.80556
102	8/18	11:00	407:20	24440	16.97222

Appendix 3. Samples and analyses for conductivity and temperature

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
Bkgrd	31-Jul-2001	15:00	38	2	38	0	0	0	38	0
Bkgrd	01-Aug-2001	07:00	50	5	50	5	0	0	55	0
Inject	01-Aug-2001	11:40	13	0	13	0	0	0	13	0
1	01-Aug-2001	13:00	32	3	32	3	0	0	35	0
2	01-Aug-2001	16:00	34	6	32	6	0	2	40	0
3	01-Aug-2001	20:00	50	4	50	4	0	0	54	0
4	02-Aug-2001	00:14	50	5	50	5	0	0	55	0
5	02-Aug-2001	06:30	52	5	50	5	1	1	57	0
6	02-Aug-2001	11:00	51	5	50	5	0	1	56	0
7	02-Aug-2001	15:00	51	5	50	5	0	1	32	24
8	02-Aug-2001	19:00	51	5	50	5	0	1	25	31
9	02-Aug-2001	22:00	51	5	50	5	0	1	26	30
10	03-Aug-2001	01:00	51	5	50	5	0	1	21	35
11	03-Aug-2001	04:00	51	5	50	5	0	1	26	30
12	03-Aug-2001	07:00	50	5	50	5	0	0	28	27
13	03-Aug-2001	10:00	50	5	50	5	0	0	55	0
14	03-Aug-2001	14:00	51	5	50	5	0	1	32	24
15	03-Aug-2001	17:00	50	5	49	5	0	1	31	24
16	03-Aug-2001	20:00	50	4	49	4	0	1	25	29
17	03-Aug-2001	23:00	50	6	49	6	0	1	56	0
18	04-Aug-2001	07:00	50	6	50	6	0	0	56	0
19	04-Aug-2001	11:00	50	6	50	6	0	0	56	0
20	04-Aug-2001	15:00	50	5	50	5	0	0	55	0
21	04-Aug-2001	19:00	50	5	49	5	0	1	55	0
22	04-Aug-2001	23:00	50	5	49	5	0	1	55	0
23	05-Aug-2001	03:00	50	5	49	5	0	1	20	35
24	05-Aug-2001	07:00	49	6	49	6	0	0	55	0
25	05-Aug-2001	11:00	50	7	50	7	0	0	57	0
26	05-Aug-2001	15:00	50	6	49	6	0	1	56	0
27	05-Aug-2001	19:00	50	5	49	5	0	1	55	0
28	05-Aug-2001	23:00	50	5	49	5	0	1	55	0
29	06-Aug-2001	03:00	50	6	49	6	0	1	27	29
30	06-Aug-2001	07:00	50	5	49	5	0	1	55	0
31	06-Aug-2001	11:00	50	5	49	5	0	1	55	0
32	06-Aug-2001	15:00	51	5	49	5	1	1	56	0
33	06-Aug-2001	19:00	51	5	49	5	1	1	56	0
34	06-Aug-2001	23:00	51	5	49	5	1	1	56	0
35	07-Aug-2001	04:00	51	5	49	5	1	1	22	34

Appendix 3. Samples and analyses for conductivity and temperature (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
36	07-Aug-2001	07:00	51	5	49	5	1	1	56	0
37	07-Aug-2001	11:00	51	5	49	5	1	1	56	0
38	07-Aug-2001	15:00	51	5	49	5	1	1	56	0
39	07-Aug-2001	19:00	50	5	49	5	0	1	55	0
40	07-Aug-2001	23:00	51	5	49	5	1	1	56	0
41	08-Aug-2001	03:00	51	5	49	5	1	1	25	31
42	08-Aug-2001	07:00	51	5	49	5	1	1	56	0
43	08-Aug-2001	11:00	51	5	49	5	1	1	56	0
44	08-Aug-2001	15:00	51	5	49	5	1	1	56	0
45	08-Aug-2001	19:00	51	5	49	5	1	1	56	0
46	08-Aug-2001	23:00	51	5	49	5	1	1	56	0
47	09-Aug-2001	03:00	51	5	49	5	1	1	21	35
48	09-Aug-2001	07:00	51	7	49	7	1	1	58	0
49	09-Aug-2001	11:00	51	6	49	6	1	1	57	0
50	09-Aug-2001	15:00	51	5	49	5	1	1	56	0
51	09-Aug-2001	19:00	51	5	49	5	1	1	56	0
52	09-Aug-2001	23:00	51	5	49	5	1	1	56	0
53	10-Aug-2001	03:00	51	5	49	5	1	1	28	28
54	10-Aug-2001	07:00	52	5	49	5	2	1	57	0
55	10-Aug-2001	11:00	49	5	49	5	0	0	54	0
56	10-Aug-2001	15:00	49	5	49	5	0	0	54	0
57	10-Aug-2001	19:00	50	4	49	4	0	1	54	0
58	10-Aug-2001	23:00	51	5	49	5	1	1	56	0
59	11-Aug-2001	03:00	51	5	49	5	1	1	20	36
60	11-Aug-2001	07:00	51	6	49	6	1	1	57	0
61	11-Aug-2001	11:00	51	5	49	5	1	1	56	0
62	11-Aug-2001	15:00	51	5	49	5	1	1	56	0
63	11-Aug-2001	19:00	51	5	49	5	1	1	56	0
64	11-Aug-2001	23:00	50	5	49	5	0	1	55	0
65	12-Aug-2001	03:00	52	5	49	5	2	1	21	36
66	12-Aug-2001	07:00	51	5	49	5	1	1	56	0
67	12-Aug-2001	11:00	51	5	49	5	1	1	56	0
68	12-Aug-2001	15:00	51	5	49	5	1	1	56	0
69	12-Aug-2001	19:00	52	4	49	4	2	1	56	0
70	12-Aug-2001	23:00	51	5	49	5	1	1	56	0
71	13-Aug-2001	03:00	51	5	49	5	1	1	27	29
72	13-Aug-2001	07:00	50	5	49	5	1	0	55	0

Appendix 3. Samples and analyses for conductivity and temperature (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
73	13-Aug-2001	11:00	50	5	49	5	1	0	55	0
74	13-Aug-2001	15:00	51	5	49	5	1	1	56	0
75	13-Aug-2001	19:00	52	4	49	4	2	1	56	0
76	13-Aug-2001	23:00	51	5	49	5	1	1	56	0
77	14-Aug-2001	03:00	51	5	49	5	1	1	27	29
78	14-Aug-2001	07:00	52	4	49	4	2	1	56	0
79	14-Aug-2001	11:00	51	5	49	5	1	1	56	0
80	14-Aug-2001	15:00	51	5	49	5	1	1	56	0
81	14-Aug-2001	19:00	51	5	49	5	1	1	56	0
82	14-Aug-2001	23:00	51	5	49	5	1	1	56	0
83	15-Aug-2001	03:00	52	4	49	4	2	1	27	29
84	15-Aug-2001	07:00	51	4	49	4	1	1	55	0
85	15-Aug-2001	11:00	50	5	49	5	1	0	55	0
86	15-Aug-2001	15:00	51	5	49	5	1	1	56	0
87	15-Aug-2001	19:00	51	5	49	5	1	1	56	0
88	15-Aug-2001	23:00	51	5	49	5	1	1	56	0
89	16-Aug-2001	03:00	51	5	49	5	1	1	33	23
90	16-Aug-2001	07:00	52	4	49	4	2	1	56	0
91	16-Aug-2001	11:00	52	4	49	4	2	1	56	0
92	16-Aug-2001	15:00	51	5	49	5	1	1	56	0
93	16-Aug-2001	19:00	51	5	49	5	1	1	56	0
94	16-Aug-2001	23:00	51	5	49	5	1	1	27	29
95	17-Aug-2001	03:00	51	4	49	4	1	1	24	31
96	17-Aug-2001	07:00	51	5	49	5	1	1	56	0
97	17-Aug-2001	11:00	51	5	49	5	1	1	27	29
98	17-Aug-2001	19:00	7	1	6	1	0	1	8	0
99	17-Aug-2001	23:00	7	1	6	1	0	1	8	0
100	18-Aug-2001	03:00	7	1	6	1	0	1	8	0
101	18-Aug-2001	07:00	7	1	6	1	0	1	8	0
102	18-Aug-2001	11:00	7	1	6	1	0	1	8	0
	Total		5024	497	4866	495	70	88	4802	717

Appendix 4. Visually selected conductivity outliers at well A1

Sample Event	Sample Number	Event Date	Sample Time	Field Cond. uS/cm	Lab Cond. uS/cm	Value Used uS/cm	Source of Value Used
49	A1-4	09-Aug-2001	11:10	885	853	853	Lab
50	A1-1	09-Aug-2001	15:12	1538	1497	1497	Lab
50	A1-4	09-Aug-2001	15:12	857	815	815	Lab
51	A1-10	09-Aug-2001	19:12	546	538	538	Lab
51	A1-11	09-Aug-2001	19:15	531	523	523	Lab
51	A1-12	09-Aug-2001	19:15	300	292	292	Lab
51	A1-4	09-Aug-2001	19:12	1418	1398	1398	Lab
51	A1-7	09-Aug-2001	19:12	815	812	815	Field
51	A1-9	09-Aug-2001	19:12	676	673	676	Field
52	A1-10	09-Aug-2001	23:12	482	469	469	Lab
52	A1-4	09-Aug-2001	23:12	1124	1072	1072	Lab
52	A1-7	09-Aug-2001	23:12	934	898	898	Lab
52	A1-8	09-Aug-2001	23:12	943	909	909	Lab
52	A1-9	09-Aug-2001	23:12	634	615	615	Lab
53	A1-3	10-Aug-2001	03:10	2067	2018	2018	Lab
53	A1-7	10-Aug-2001	03:10	748	809	809	Lab
54	A1-10	10-Aug-2001	07:01	409	402	409	Field
54	A1-14	10-Aug-2001	06:58	125	215	215	Lab
54	A1-8	10-Aug-2001	07:01	763	733	733	Lab
54	A1-9	10-Aug-2001	07:01	510	499	499	Lab
55	A1-1	10-Aug-2001	11:20	2080	1950	1950	Lab
55	A1-2	10-Aug-2001	11:20	2158	2004	2004	Lab
56	A1-11	10-Aug-2001	15:05	606	596	596	Lab
56	A1-12	10-Aug-2001	15:05	382	372	372	Lab
56	A1-13	10-Aug-2001	15:05	297	283	283	Lab
57	A1-11	10-Aug-2001	19:10	697	694	697	Field
57	A1-12	10-Aug-2001	19:10	404	399	404	Field
57	A1-13	10-Aug-2001	19:10	312	306	312	Field
57	A1-2	10-Aug-2001	19:07	1554	1517	1517	Lab
57	A1-3	10-Aug-2001	19:07	1269	1229	1229	Lab
58	A1-1	10-Aug-2001	23:09	1729	2109	2109	Lab
58	A1-3	10-Aug-2001	23:09	2237	2115	2115	Lab
64	A1-1	11-Aug-2001	23:06	1234	1188	1188	Lab
64	A1-11	11-Aug-2001	23:10	641	629	629	Lab
64	A1-12	11-Aug-2001	23:10	395	386	386	Lab
64	A1-2	11-Aug-2001	23:06	1216	1173	1173	Lab
64	A1-3	11-Aug-2001	23:06	1384	1333	1333	Lab
64	A1-4	11-Aug-2001	23:06	1447	1386	1386	Lab
64	A1-8	11-Aug-2001	23:06	1704	1645	1645	Lab
64	A1-9	11-Aug-2001	23:06	987	955	955	Lab

Appendix 4. Visually selected conductivity outliers at well A1 (continued)

Sample Event	Sample Number	Event Date	Sample Time	Field Cond. uS/cm	Lab Cond. uS/cm	Value Used uS/cm	Source of Value Used
65	A1-1	12-Aug-2001	03:17	1418	1143	1143	Lab
65	A1-10	12-Aug-2001	03:17	927	747	747	Lab
65	A1-11	12-Aug-2001	03:16	793	645	645	Lab
65	A1-12	12-Aug-2001	03:16	491	400	400	Lab
65	A1-13	12-Aug-2001	03:16	321	265	265	Lab
65	A1-14	12-Aug-2001	03:16	280	223	223	Lab
65	A1-15	12-Aug-2001	03:16	251	202	202	Lab
65	A1-2	12-Aug-2001	03:17	1364	1104	1104	Lab
65	A1-3	12-Aug-2001	03:17	1543	1239	1239	Lab
65	A1-4	12-Aug-2001	03:17	1664	1338	1338	Lab
65	A1-5	12-Aug-2001	03:17	2416	1939	1939	Lab
65	A1-6	12-Aug-2001	03:17	2474	2013	2013	Lab
65	A1-7	12-Aug-2001	03:17	2372	1896	1896	Lab
65	A1-8	12-Aug-2001	03:17	2188	1755	1755	Lab
65	A1-9	12-Aug-2001	03:17	1266	1029	1029	Lab
66	A1-5	12-Aug-2001	07:02	1928	1966	1966	Lab
72	A1-5	13-Aug-2001	07:03	1127	1959	1959	Lab
73	A1-10	13-Aug-2001	11:06	926	917	917	Lab
73	A1-11	13-Aug-2001	11:08	771	762	762	Lab
73	A1-12	13-Aug-2001	11:08	659	655	659	Field
73	A1-13	13-Aug-2001	11:08	600	590	590	Lab
73	A1-14	13-Aug-2001	11:08	333	330	333	Field
73	A1-15	13-Aug-2001	11:08	232	224	224	Lab
73	A1-5	13-Aug-2001	11:06	2546	2452	2452	Lab
73	A1-8	13-Aug-2001	11:06	2112	2059	2059	Lab
73	A1-9	13-Aug-2001	11:06	1261	1229	1229	Lab
74	A1-1	13-Aug-2001	15:06	1107	1087	1087	Lab
74	A1-10	13-Aug-2001	15:06	967	956	956	Lab
74	A1-11	13-Aug-2001	15:08	811	816	811	Field
74	A1-12	13-Aug-2001	15:08	628	633	628	Field
74	A1-7	13-Aug-2001	15:06	2294	2261	2261	Lab
75	A1-2	13-Aug-2001	19:04	1886	1074	1074	Lab
75	A1-3	13-Aug-2001	19:04	1524	1497	1497	Lab
75	A1-4	13-Aug-2001	19:04	1487	1468	1468	Lab
75	A1-6	13-Aug-2001	19:04	2443	2399	2399	Lab
75	A1-7	13-Aug-2001	19:04	2291	2240	2240	Lab
78	A1-7	14-Aug-2001	07:57	2018	1972	1972	Lab
80	A1-9	14-Aug-2001	15:06	640	739	739	Lab
82	A1-4	14-Aug-2001	23:14	1113	1223	1223	Lab
83	A1-11	15-Aug-2001	03:05	455	488	488	Lab

Appendix 4. Visually selected conductivity outliers at well A1 (continued)

Sample Event	Sample Number	Event Date	Sample Time	Field Cond. uS/cm	Lab Cond. uS/cm	Value Used uS/cm	Source of Value Used
83	A1-12	15-Aug-2001	03:05	319	453	453	Lab
83	A1-13	15-Aug-2001	03:05	278	319	319	Lab
83	A1-14	15-Aug-2001	03:05	212	280	280	Lab
83	A1-6	15-Aug-2001	03:07	1775	2042	2042	Lab
83	A1-7	15-Aug-2001	03:07	955	1737	1737	Lab
83	A1-8	15-Aug-2001	03:07	634	944	944	Lab
83	A1-9	15-Aug-2001	03:07	511	632	632	Lab
84	A1-15	15-Aug-2001	07:00	209	210	209	Field
84	A1-3	15-Aug-2001	07:00	1013	1016	1013	Field
84	A1-4	15-Aug-2001	07:00	1177	1168	1168	Lab
85	A1-11	15-Aug-2001	11:03	519	522	519	Field
85	A1-12	15-Aug-2001	11:03	523	528	523	Field
85	A1-13	15-Aug-2001	11:03	579	588	588	Lab
85	A1-14	15-Aug-2001	11:03	390	394	390	Field
85	A1-15	15-Aug-2001	11:03	263	264	263	Field
85	A1-2	15-Aug-2001	11:09	793	791	793	Field
85	A1-3	15-Aug-2001	11:09	1407	1411	1407	Field
85	A1-8	15-Aug-2001	11:09	1443	1426	1426	Lab
86	A1-2	15-Aug-2001	15:02	994	992	994	Field
86	A1-4	15-Aug-2001	15:02	1467	1454	1454	Lab
86	A1-6	15-Aug-2001	15:02	2126	2087	2087	Lab
87	A1-10	15-Aug-2001	19:08	319	315	319	Field
87	A1-6	15-Aug-2001	19:08	1338	1332	1338	Field
87	A1-7	15-Aug-2001	19:08	1147	1129	1129	Lab
87	A1-8	15-Aug-2001	19:08	4	547	547	Lab
87	A1-9	15-Aug-2001	19:08	339	333	339	Field
88	A1-9	15-Aug-2001	23:07	357	368	368	Lab
89	A1-8	16-Aug-2001	03:17	1805	1789	1789	Lab
91	A1-9	16-Aug-2001	11:07	601	620	620	Lab
92	A1-9	16-Aug-2001	15:07	410	402	402	Lab
95	A1-16	17-Aug-2001	03:08	661	654	661	Field

Appendix 5. Samples and analyses for uranine

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
Bkgrd	31-Jul-2001	15:00	38	2	38	2	0	0	40	0
Bkgrd	01-Aug-2001	07:00	50	5	50	5	0	0	55	0
Inject	01-Aug-2001	11:40	13	0	13	0	0	0	13	0
1	01-Aug-2001	13:00	32	3	32	3	0	0	35	0
2	01-Aug-2001	16:00	34	6	32	3	0	0	35	0
3	01-Aug-2001	20:00	50	4	50	4	0	0	54	0
4	02-Aug-2001	00:14	50	5	50	5	0	0	55	0
5	02-Aug-2001	06:30	52	5	50	5	1	1	57	0
6	02-Aug-2001	11:00	51	5	50	5	0	0	55	0
7	02-Aug-2001	15:00	51	5	50	5	0	1	56	0
8	02-Aug-2001	19:00	51	5	26	0	0	1	27	0
9	02-Aug-2001	22:00	51	5	26	0	0	1	27	0
10	03-Aug-2001	01:00	51	5	20	0	0	0	20	0
11	03-Aug-2001	04:00	51	5	26	0	0	0	26	0
12	03-Aug-2001	07:00	50	5	26	2	0	0	28	0
13	03-Aug-2001	10:00	50	5	50	5	0	0	55	0
14	03-Aug-2001	14:00	51	5	31	0	0	0	31	0
15	03-Aug-2001	17:00	50	5	30	0	0	0	30	0
16	03-Aug-2001	20:00	50	4	25	0	0	0	25	0
17	03-Aug-2001	23:00	50	6	49	5	0	1	55	0
18	04-Aug-2001	07:00	50	6	50	6	0	0	56	0
19	04-Aug-2001	11:00	50	6	50	6	0	0	56	0
20	04-Aug-2001	15:00	50	5	50	5	0	0	55	0
21	04-Aug-2001	19:00	50	5	49	5	0	1	55	0
22	04-Aug-2001	23:00	50	5	49	5	0	1	55	0
23	05-Aug-2001	03:00	50	5	20	0	0	0	20	0
24	05-Aug-2001	07:00	49	6	49	5	0	0	54	0
25	05-Aug-2001	11:00	50	7	49	5	0	0	54	0
26	05-Aug-2001	15:00	50	6	47	6	0	1	54	0
27	05-Aug-2001	19:00	50	5	49	6	0	1	56	0
28	05-Aug-2001	23:00	50	5	49	5	0	1	55	0
29	06-Aug-2001	03:00	50	6	20	5	0	1	26	0
30	06-Aug-2001	07:00	50	5	49	5	0	1	55	0
31	06-Aug-2001	11:00	50	5	49	5	0	1	55	0
32	06-Aug-2001	15:00	51	5	49	5	2	1	57	0
33	06-Aug-2001	19:00	51	5	49	5	1	1	56	0
34	06-Aug-2001	23:00	51	5	49	5	1	1	56	0
35	07-Aug-2001	04:00	51	5	20	2	0	0	22	0

Appendix 5. Samples and analyses for uranine (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
36	07-Aug-2001	07:00	51	5	49	5	1	1	56	0
37	07-Aug-2001	11:00	51	5	49	5	1	1	56	0
38	07-Aug-2001	15:00	51	5	49	5	1	1	56	0
39	07-Aug-2001	19:00	50	5	49	5	0	1	55	0
40	07-Aug-2001	23:00	51	5	49	5	1	1	56	0
41	08-Aug-2001	03:00	51	5	20	2	1	1	24	0
42	08-Aug-2001	07:00	51	5	49	5	1	1	56	0
43	08-Aug-2001	11:00	51	5	49	5	1	1	56	0
44	08-Aug-2001	15:00	51	5	49	5	1	1	56	0
45	08-Aug-2001	19:00	51	5	49	5	1	1	56	0
46	08-Aug-2001	23:00	51	5	49	5	1	1	56	0
47	09-Aug-2001	03:00	51	5	20	0	1	0	21	0
48	09-Aug-2001	07:00	51	7	49	7	1	1	58	0
49	09-Aug-2001	11:00	51	6	49	5	1	1	56	0
50	09-Aug-2001	15:00	51	5	49	5	1	1	56	0
51	09-Aug-2001	19:00	51	5	49	5	1	1	56	0
52	09-Aug-2001	23:00	51	5	49	4	1	1	55	0
53	10-Aug-2001	03:00	51	5	20	5	1	1	27	0
54	10-Aug-2001	07:00	52	5	48	5	2	1	56	0
55	10-Aug-2001	11:00	49	5	49	5	0	0	54	0
56	10-Aug-2001	15:00	49	5	49	5	0	0	54	0
57	10-Aug-2001	19:00	50	4	49	4	0	1	54	0
58	10-Aug-2001	23:00	51	5	49	5	1	1	56	0
59	11-Aug-2001	03:00	51	5	20	0	0	0	20	0
60	11-Aug-2001	07:00	51	6	49	6	1	1	57	0
61	11-Aug-2001	11:00	51	5	49	5	1	1	56	0
62	11-Aug-2001	15:00	51	5	49	4	1	1	55	0
63	11-Aug-2001	19:00	51	5	49	4	1	1	55	0
64	11-Aug-2001	23:00	50	5	49	4	1	1	55	0
65	12-Aug-2001	03:00	52	5	20	0	0	1	21	0
66	12-Aug-2001	07:00	51	5	49	5	1	1	56	0
67	12-Aug-2001	11:00	51	5	49	5	1	1	56	0
68	12-Aug-2001	15:00	51	5	49	5	1	1	56	0
69	12-Aug-2001	19:00	52	4	49	4	2	1	56	0
70	12-Aug-2001	23:00	51	5	49	4	1	1	55	0
71	13-Aug-2001	03:00	51	5	20	4	1	1	26	0
72	13-Aug-2001	07:00	50	5	49	5	1	0	55	0
73	13-Aug-2001	11:00	50	5	49	5	1	0	55	0
74	13-Aug-2001	15:00	51	5	49	5	1	1	56	0

Appendix 5. Samples and analyses for uranine (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
75	13-Aug-2001	19:00	52	4	49	4	2	1	56	0
76	13-Aug-2001	23:00	51	5	49	4	1	1	55	0
77	14-Aug-2001	03:00	51	5	20	4	1	1	26	0
78	14-Aug-2001	07:00	52	4	49	4	2	1	56	0
79	14-Aug-2001	11:00	51	5	49	5	1	1	56	0
80	14-Aug-2001	15:00	51	5	49	5	1	1	56	0
81	14-Aug-2001	19:00	51	5	49	5	1	1	56	0
82	14-Aug-2001	23:00	51	5	49	4	1	1	55	0
83	15-Aug-2001	03:00	52	4	20	4	2	1	27	0
84	15-Aug-2001	07:00	51	4	49	4	1	1	55	0
85	15-Aug-2001	11:00	50	5	49	5	1	0	55	0
86	15-Aug-2001	15:00	51	5	49	5	1	1	56	0
87	15-Aug-2001	19:00	51	5	49	5	1	1	56	0
88	15-Aug-2001	23:00	51	5	49	4	1	1	55	0
89	16-Aug-2001	03:00	51	5	26	4	1	1	32	0
90	16-Aug-2001	07:00	52	4	49	4	2	1	56	0
91	16-Aug-2001	11:00	52	4	49	4	2	1	56	0
92	16-Aug-2001	15:00	51	5	49	5	1	1	56	0
93	16-Aug-2001	19:00	51	5	49	5	1	1	56	0
94	16-Aug-2001	23:00	51	5	26	0	0	1	27	0
95	17-Aug-2001	03:00	51	4	0	0	0	0	0	0
96	17-Aug-2001	07:00	51	5	49	5	1	1	56	0
97	17-Aug-2001	11:00	51	5	26	1	0	1	28	0
98	17-Aug-2001	19:00	7	1	6	1	0	1	8	0
99	17-Aug-2001	23:00	7	1	6	1	0	1	8	0
100	18-Aug-2001	03:00	7	1	6	1	0	1	8	0
101	18-Aug-2001	07:00	7	1	6	1	0	1	8	0
102	18-Aug-2001	11:00	7	1	6	1	0	1	8	0
	Total		5024	497	4237	402	65	75	4779	0

Appendix 6. Samples and analyses for pH

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
Bkgrd	31-Jul-2001	15:00	38	2	37	0	0	0	37	0
Bkgrd	01-Aug-2001	07:00	50	5	8	5	0	0	13	0
Inject	01-Aug-2001	11:40	13	0	13	1	0	0	14	0
1	01-Aug-2001	13:00	32	3	6	0	0	0	6	0
2	01-Aug-2001	16:00	34	6	5	0	0	0	5	0
3	01-Aug-2001	20:00	50	4	6	0	0	0	6	0
4	02-Aug-2001	00:14	50	5	5	0	0	0	5	0
5	02-Aug-2001	06:30	52	5	50	5	1	1	57	0
6	02-Aug-2001	11:00	51	5	50	5	0	1	56	0
7	02-Aug-2001	15:00	51	5	49	5	0	1	55	0
8	02-Aug-2001	19:00	51	5	18	0	0	0	18	0
9	02-Aug-2001	22:00	51	5	0	0	0	0	0	0
10	03-Aug-2001	01:00	51	5	0	0	0	0	0	0
11	03-Aug-2001	04:00	51	5	0	0	0	0	0	0
12	03-Aug-2001	07:00	50	5	0	0	0	0	0	0
13	03-Aug-2001	10:00	50	5	0	0	0	0	0	0
14	03-Aug-2001	14:00	51	5	18	0	0	0	18	0
15	03-Aug-2001	17:00	50	5	29	0	0	0	29	0
16	03-Aug-2001	20:00	50	4	24	0	0	0	24	0
17	03-Aug-2001	23:00	50	6	0	0	0	0	0	0
18	04-Aug-2001	07:00	50	6	0	0	0	0	0	0
19	04-Aug-2001	11:00	50	6	0	0	0	0	0	0
20	04-Aug-2001	15:00	50	5	0	0	0	0	0	0
21	04-Aug-2001	19:00	50	5	0	0	0	0	0	0
22	04-Aug-2001	23:00	50	5	0	0	0	0	0	0
23	05-Aug-2001	03:00	50	5	0	0	0	0	0	0
24	05-Aug-2001	07:00	49	6	0	0	0	0	0	0
25	05-Aug-2001	11:00	50	7	0	0	0	0	0	0
26	05-Aug-2001	15:00	50	6	0	0	0	0	0	0
27	05-Aug-2001	19:00	50	5	0	0	0	0	0	0
28	05-Aug-2001	23:00	50	5	0	0	0	0	0	0
29	06-Aug-2001	03:00	50	6	0	0	0	0	0	0
30	06-Aug-2001	07:00	50	5	0	0	0	0	0	0
31	06-Aug-2001	11:00	50	5	0	0	0	0	0	0
32	06-Aug-2001	15:00	51	5	15	1	2	1	19	0
33	06-Aug-2001	19:00	51	5	11	0	0	1	12	0
34	06-Aug-2001	23:00	51	5	16	2	1	0	19	0
35	07-Aug-2001	04:00	51	5	0	0	0	0	0	0

Appendix 6. Samples and analyses for pH (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
36	07-Aug-2001	07:00	51	5	0	0	0	0	0	0
37	07-Aug-2001	11:00	51	5	0	0	0	0	0	0
38	07-Aug-2001	15:00	51	5	11	1	1	0	13	0
39	07-Aug-2001	19:00	50	5	11	1	0	0	12	0
40	07-Aug-2001	23:00	51	5	11	0	1	1	13	0
41	08-Aug-2001	03:00	51	5	4	2	1	1	8	0
42	08-Aug-2001	07:00	51	5	11	1	0	0	12	0
43	08-Aug-2001	11:00	51	5	23	4	1	1	29	0
44	08-Aug-2001	15:00	51	5	49	5	1	1	56	0
45	08-Aug-2001	19:00	51	5	49	5	1	1	56	0
46	08-Aug-2001	23:00	51	5	11	0	0	0	11	0
47	09-Aug-2001	03:00	51	5	0	0	0	0	0	0
48	09-Aug-2001	07:00	51	7	0	0	0	0	0	0
49	09-Aug-2001	11:00	51	6	0	0	0	0	0	0
50	09-Aug-2001	15:00	51	5	14	0	1	0	15	0
51	09-Aug-2001	19:00	51	5	13	1	1	0	15	0
52	09-Aug-2001	23:00	51	5	7	0	0	0	7	0
53	10-Aug-2001	03:00	51	5	3	0	0	0	3	0
54	10-Aug-2001	07:00	52	5	6	0	0	0	6	0
55	10-Aug-2001	11:00	49	5	7	0	0	0	7	0
56	10-Aug-2001	15:00	49	5	49	5	0	0	54	0
57	10-Aug-2001	19:00	50	4	49	4	0	1	54	0
58	10-Aug-2001	23:00	51	5	7	0	0	0	7	0
59	11-Aug-2001	03:00	51	5	0	0	0	0	0	0
60	11-Aug-2001	07:00	51	6	0	0	0	0	0	0
61	11-Aug-2001	11:00	51	5	0	0	0	0	0	0
62	11-Aug-2001	15:00	51	5	0	0	0	0	0	0
63	11-Aug-2001	19:00	51	5	3	0	0	0	3	0
64	11-Aug-2001	23:00	50	5	20	0	0	0	20	0
65	12-Aug-2001	03:00	52	5	6	0	0	0	6	0
66	12-Aug-2001	07:00	51	5	8	0	0	0	8	0
67	12-Aug-2001	11:00	51	5	9	0	1	0	10	0
68	12-Aug-2001	15:00	51	5	9	0	0	0	9	0
69	12-Aug-2001	19:00	52	4	10	2	2	0	14	0
70	12-Aug-2001	23:00	51	5	12	0	1	0	13	0
71	13-Aug-2001	03:00	51	5	5	1	1	1	8	0
72	13-Aug-2001	07:00	50	5	8	0	0	0	8	0
73	13-Aug-2001	11:00	50	5	12	0	1	0	13	0

Appendix 6. Samples and analyses for pH (continued)

			collected		analyzed					
Event	Date	Time	# samples	# QC	# samples	# QC	B3	B6(outflow)	Field	Lab
74	13-Aug-2001	15:00	51	5	10	1	0	0	11	0
75	13-Aug-2001	19:00	52	4	10	1	0	1	12	0
76	13-Aug-2001	23:00	51	5	25	3	1	1	30	0
77	14-Aug-2001	03:00	51	5	0	0	0	0	0	0
78	14-Aug-2001	07:00	52	4	6	1	0	0	7	0
79	14-Aug-2001	11:00	51	5	7	0	1	0	8	0
80	14-Aug-2001	15:00	51	5	9	1	1	0	11	0
81	14-Aug-2001	19:00	51	5	12	2	1	0	15	0
82	14-Aug-2001	23:00	51	5	26	0	1	0	27	0
83	15-Aug-2001	03:00	52	4	6	3	2	1	12	0
84	15-Aug-2001	07:00	51	4	7	0	1	0	8	0
85	15-Aug-2001	11:00	50	5	7	0	1	0	8	0
86	15-Aug-2001	15:00	51	5	17	4	1	1	23	0
87	15-Aug-2001	19:00	51	5	9	1	1	1	12	0
88	15-Aug-2001	23:00	51	5	20	0	1	0	21	0
89	16-Aug-2001	03:00	51	5	8	0	1	0	9	0
90	16-Aug-2001	07:00	52	4	7	0	1	0	8	0
91	16-Aug-2001	11:00	52	4	6	0	1	1	8	0
92	16-Aug-2001	15:00	51	5	20	5	1	1	27	0
93	16-Aug-2001	19:00	51	5	49	5	1	1	56	0
94	16-Aug-2001	23:00	51	5	0	0	0	0	0	0
95	17-Aug-2001	03:00	51	4	0	0	0	0	0	0
96	17-Aug-2001	07:00	51	5	8	0	1	1	10	0
97	17-Aug-2001	11:00	51	5	2	0	0	0	2	0
98	17-Aug-2001	19:00	7	1	2	1	0	1	4	0
99	17-Aug-2001	23:00	7	1	6	1	0	0	7	0
100	18-Aug-2001	03:00	7	1	6	1	0	1	8	0
101	18-Aug-2001	07:00	7	1	6	0	0	0	6	0
102	18-Aug-2001	11:00	7	1	6	0	0	0	6	0
	Total		5024	497	1094	86	36	23	1239	0